Introduction to Engineering: A Case Study of an Interdisciplinary Course in Mathematics, Science, and Technology

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Abstract

This thesis research was a qualitative case study of a single class of *Interdisciplinary Studies: Introduction to Engineering* taught in a secondary school. The study endeavoured to explore students' experiences in and perceptions of the course, and to investigate the viability of engineering as an interdisciplinary theme at the secondary school level. Data were collected in the form of student questionnaires, the researcher's observations and reflections, and artefacts representative of students' work. Data analysis was performed by coding textual data and classifying text segments into common themes. The themes that emerged from the data were aligned with facets of interdisciplinary study, including making connections, project-based learning, and student engagement and affective outcomes. The findings of the study showed that students were positive about their experiences in the course, and enjoyed its project-driven nature. Content from mathematics, physics, and technological design was easily integrated under the umbrella of engineering. Students felt that the opportunity to develop problem solving and teamwork skills were two of the most important aspects of the course and could be relevant not only for engineering, but for other disciplines or their day-to-day lives after secondary school. The study concluded that engineering education in secondary school can be a worthwhile experience for a variety of students and not just those intending postsecondary study in engineering. This has implications for the inclusion of engineering in the secondary school curriculum and can inform the practice of curriculum planners at the school, school board, and provincial levels. Suggested directions for further research include classroom-based action research in the areas of technological education, engineering education in secondary school, and interdisciplinary education.

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Table of Contents

Page

List of Tables

Table Page

List of Figures

CHAPTER ONE: INTRODUCTION TO THE PROBLEM

I entered the teaching profession as an anomaly: a technological education (TE) teacher with an engineering degree and work experience as a professional engineer. The integration of mathematics, science, and technology seemed natural and obvious to me. When I began teaching, I found that TE departments in secondary schools were often alienated from the academic departments. The courses, the students, and even the teachers were different from those found elsewhere in the school. Unlike their academic colleagues, the TE teachers typically held trade certificates rather than degrees and kept to themselves in the TE wing of the school. The courses were project-driven and student-centered, unlike a typical academic class, and it seemed that students were often counselled into TE courses if they struggled in a traditional classroom setting. Additionally, the academic subjects were still taught as separate, discrete disciplines, as they were when I was a student. The study of engineering as a unique discipline was essentially missing from the Ontario secondary school curriculum.

I have long believed that there is untapped potential to address the lack of engineering in the curriculum while promoting TE through the integration of academic and technological subject disciplines. In the fall of 2007, while taking a Master of Education course that focused on innovative curriculum, I conceived a course that integrates mathematics, science, and technology under the umbrella of engineering. Realizing that it would be possible to offer such a course under the Ontario curriculum's *Interdisciplinary Studies* document, I proposed an interdisciplinary pre-engineering course to the leadership team at my school. They were supportive of the idea and included the course in the school's program booklet. *Introduction to Engineering* was established in February 2009.

The purpose of this research was to perform a qualitative case study investigating an *Introduction to Engineering* course over the course of a semester. This included students' perceptions, their activities, and artefacts that they produced, as well as my own observations and reflections as the designer and teacher of the course. The study explored engineering as an organizing theme for an interdisciplinary course and students' experiences in an integrated mathematics, science, and technology course.

Background of the Problem

Technological education, technology education, technical studies, career and technical education, technological studies, engineering and technology studies, industrial arts, industrial technology, manual arts, practical and applied arts, and vocational education are all terms used to identify the study of technology in secondary schools in Canada, the United States, and abroad (Gardner & Hill, 1999a; Spencer & Rogers, 2006). Adding to the confusion around nomenclature for the field is that the word *technology* brings to mind computers for many people, so technological education is sometimes thought to be a synonym for educational technology or information communication technology (ICT). This study will use the term *technological education* (TE), which is consistent with the terminology used in the Ontario curriculum (Ministry of Education, 2009) for the study of technology in all its forms. Gardner and Hill further define technological education as:

> that part of the curriculum concerned with helping learners to become technologically capable: to identify human needs for which technological

solutions are possible, to design and make appropriate products (physical artefacts or organisational systems), and to evaluate their quality and their potential societal and environmental effects. (1999a, p. 104)

Can engineering bridge the century-old gap between TE and academic subject disciplines? The provenance of TE is in the industrial revolution of the late 19th century, when vocational education was established as a separate education system with a mandate of providing skilled labour to rapidly growing industries (Lynch, 1997). Today, in the early 21st century, there is still a divide between TE and academic subject disciplines. Despite name changes for the field and attempts at curriculum reform, the image of TE as manual skills training persists. This image is not wholly unwarranted, as a focus on narrow tool skills continues to be the dominant teaching practice in TE (Hayward, 2004; Petrina & Dalley, 2003; Zuga, 1997).

Although some countries such as England, New Zealand, and Australia have shifted away from a focus on skills training, it endures in Ontario (Gardner & Hill, 1999b). Secondary school students and their parents hold TE, its programs, and the postsecondary pathways it promotes in low esteem relative to academic subject disciplines (Gardner & Hill, 1999b; Petrina & Dalley, 2003). Worldwide, enrolment in TE has been declining, despite increases in overall school enrolment and an increasingly technological world (Gradwell & Welch, 2003; Smaller, 2000). Engineering is seen as one way of raising the status of TE and making it more acceptable to students and their parents.

Engineering is often referred to as an invisible profession, despite the fact that there are more than 234,000 professional engineers in Canada (Engineers Canada, 2010).

Engineers' work often goes unnoticed and is not well understood by the general public. Rudimentary definitions of engineering most often describe it as the application of scientific knowledge and mathematical principles to practical ends. Attempts to define the broad and varied field of engineering succinctly are consistent in describing engineering as a profession that utilizes science, mathematics, and technology (Lewis, 2004).

In Ontario, secondary school students are streamed according to their intended postsecondary pathways. In Grades 11 and 12, courses are categorized as university preparation, university/college preparation, college preparation, and workplace preparation. Other courses are designated as open courses intended for students in all pathways. The Grade 11 and 12 TE curriculum in Ontario offers university/college, college, and workplace preparation courses in engineering-related fields such as construction, manufacturing, communications, transportation, and technological design.

Despite the prevalence of technology in engineers' work and the relevant knowledge and skills that might be acquired in TE courses, many students will enter faculties of engineering without ever taking a TE course. TE and its programs have low status in the eyes of students and parents, and university-bound students often consider TE irrelevant for them (Gardner & Hill, 1999b; Petrina & Dalley, 2003). One of the goals of *Introduction to Engineering* is to bring TE to a wider range of students, specifically students considering postsecondary studies in engineering.

Statement of the Research Context

Research in TE has been mostly quantitative, focusing predominantly on curriculum development, the place of TE in the curriculum, and defining the subject

(Petrina, 1998; Zuga, 1997). The research has been narrow, focusing on existing practices rather than exploring new ideas and new directions. Petrina's survey of research published in the *Journal of Technology Education* from 1989 to 1997 found that research in TE was conservative and orthodox, uncritical, and reflective of the predominant thinking in the field that TE should focus on vocational skills and economic purposes (Petrina 1998). Foster (1996) found that research in TE has not translated into classroom practice. Hoeplf (1997) presented a primer on qualitative research for technology educators. She encouraged TE researchers to become familiar with qualitative research and to use it to gain a deeper understanding of phenomena, new perspectives, or in-depth knowledge that is difficult to quantify. Hoeplf (1997) also suggested using qualitative research to discover variables that might be researched in later quantitative studies.

Areas that have been well-researched in other subject disciplines such as curriculum theory, cognition, problem solving, integration, teaching strategies, and inclusiveness have been neglected in TE (Hoepfl, 1997; Lewis, 1999; Zuga, 1997). Furthermore, technological literacy, students' attitudes towards TE, and research based on firsthand, on-site observations of students and teachers has been limited, and was identified as a crucial area for future TE research (Jones & Moreland, 2003; Lewis, 1999; Petrina, 1998).

The place of TE in the curriculum and the integration of TE with academic subjects are among the critical issues identified by technology educators (Foster, 1996). Published case studies of TE integrated with academic subjects in secondary school are sparse. In most instances, TE is seen as a teaching method and a means of improving achievement in mathematics and science, rather than an area of study with its own inherent value (Zuga, 1997). Through the study of the *Introduction to Engineering* course, new understanding of how interdisciplinary study can be conceptualized and enacted within a secondary school course, and the potential role of how engineering as a subject in the secondary school curriculum might be realized.

Conceptual Framework

The Ontario Grade 11 and 12 curriculum has little to offer in the study of engineering design, engineering practices, or engineering principles. The mathematics, science, and TE curricula all mention engineering as a possible postsecondary destination or career (Ministry of Education, 2007, 2008, 2009). The mathematics curriculum makes no further reference to engineering, while other references to engineering in the science curriculum are almost exclusively in the narrow context of bioengineering and genetic engineering. In the TE curriculum documents, engineering is used most often as a label for course titles, such as *Computer Engineering* or *Manufacturing Engineering*, and is sometimes used as a descriptor such as in engineering drawings. Reverse engineering is described as a problem solving method, and principles of engineering is mentioned in the preamble to the technological design course descriptions. In the previous TE curriculum (Ministry of Education, 2000), there were expectations in the Grade 12 technological design curriculum that explicitly addressed the act of engineering, using terms such as engineering design and engineering testing. However, these expectations were removed in the 2009 revision of the TE curriculum (Ministry of Education, 2009).

Introduction to Engineering was designed to address the dearth of engineering in the Ontario secondary school curriculum and to help connect TE to academic subject disciplines through the integrated study of mathematics, physics, and technological design. As a credit course in a public secondary school, it must exist within the framework of the Ontario curriculum. *Introduction to Engineering* was offered under the Ontario curriculum's *Interdisciplinary Studies* document (Ministry of Education, 2002). An activity-based, project-driven course that challenges students to collaboratively solve open-ended engineering design problems seemed ideally suited to meet the intended goals of interdisciplinary study (IDS) as stated in the document, including making connections between subject disciplines, managing information, working independently and as part of a team, assessing students through performance tasks, and using higher-order thinking skills to find innovative solutions to problems.

The curriculum provides two options for the design of an interdisciplinary course: a single credit course that combines all of the interdisciplinary expectations with a selection of expectations from two or more courses, and a multiple-credit course that combines all of the interdisciplinary expectations with all of the expectations from two or more other courses. *Introduction to Engineering* is the former model. The multidisciplinary nature and broad scope of engineering make it a suitable organizing theme for an interdisciplinary course. Selected topics and concepts from mathematics (data analysis, vectors, functions, mathematical modeling, two-dimensional and three-dimensional geometry, trigonometry), physics (forces, motion, momentum, energy, power), and technological design (structural design, technical drawing, computer assisted design, and fabrication) can easily be integrated under the umbrella of engineering.

Introduction to Engineering was intended not only to provide students with an interdisciplinary experience, but also to allow students to explore the practice and profession of engineering. The course endeavoured to give students an understanding of what engineering is and what engineers do. The course was organized under the following headings: Engineering and Society, Engineering Design, Engineering Analysis, Engineering Science, and Engineering Communication. This course outline was derived based on the thoughts and findings of TE researchers (Childress & Rhodes, 2008; Wicklein, 2006) and the curricula of existing high school engineering courses (International Technology Educators Association, 2004; Onwubiko, 1997).

Purpose of the Study

Interdisciplinary Studies: Introduction to Engineering was a Grade 12 university preparation course directed at students considering postsecondary studies in engineering. The course was offered under the Ontario curriculum's *Interdisciplinary Studies* document and integrated expectations from mathematics, physics, and technological design. The purpose of this qualitative case study was to explore the use of engineering as a theme for integrating mathematics, science, and technology, and to explore students' experiences in and perceptions of an interdisciplinary *Introduction to Engineering* course. The research questions explored in the study were:

- What are secondary school students' experiences in and perceptions of an interdisciplinary *Introduction to Engineering* course that integrates mathematics, physics, and technological design?
- What is the viability of engineering as an organizing theme for the integration of mathematics, science, and technology in the secondary school curriculum?

Importance of the Study

Engineering as a disciplinary entity is conspicuously missing from the Ontario secondary school curriculum. Grade 10 science, Grade 11 mathematics, and a Grade 11 or 12 science or TE credit are secondary school graduation requirements in Ontario. Mathematics and science are important components of engineering, but they are most often taught as discrete, separate disciplines in secondary school. In general, curriculum integration or IDS in secondary school are rare. The Ontario curriculum describes TE as a subject area relevant for all students:

> As they proceed through their elementary and secondary school education, students attain a level of technological literacy that will enhance their ability to succeed in their postsecondary studies or in the workplace. For students who do not choose to pursue careers in technology, technological education can provide knowledge and skills that will enhance their daily lives, whether by enabling them to work on home renovations or car repairs or by allowing them to pursue technological hobbies. (Ministry of Education, 2009, p.5)

However, TE is often focused on vocational training and promoted as a pathway to apprenticeships and skilled trades. IDS provides students the opportunity to experience the unique multidisciplinary problem solving that is at the heart of engineering.

A recurring theme in the literature is that research in TE is sparse (Jones & Moreland, 2003; Merrill, 2004) and that firsthand, classroom-level research of students and teachers has been limited. Most of the research in TE has been quantitative, focusing predominantly on the status of the curriculum, existing practices, and defining TE (Petrina, 1998; Zuga, 1997). Johnson and Daugherty (2008) noted that, although progress has been made in recent years, "the focus, methods, overall quality and rigor of research in technology education needs to be improved along the same lines as advocated by Zuga, Foster, and Petrina in previous decades" (p.26).

The integration of TE with academic subjects has been identified as one of the deficient areas in TE research (Foster, 1996). A survey of teachers, teacher educators, and state and regional supervisors in the US identified the place of TE in the whole school curriculum and integration of TE with academic subjects as two of the top five issues facing TE (Wicklein, 2004). This study explored, in part, whether engineering can be used to integrate TE into the educational mainstream.

This study endeavoured to explore the implementation of *Introduction to Engineering*, an interdisciplinary course in mathematics, physics, and technological design. Researching students' perceptions and experiences in the course can provide information that may be used to improve the course for future students. The study was intended to inform the practice of teachers, school administrators, department heads, and school board subject coordinators as they endeavour to introduce engineering courses or other interdisciplinary courses into their own schools. From a provincial perspective, the study of *Introduction to Engineering* may lead to the establishment of explicit courses in engineering in the Ontario curriculum and potentially move TE in Ontario in a new direction.

Scope and Limitations of the Study

Interdisciplinary Studies: Introduction to Engineering was the result of my engineering education and experience and my 15 years' teaching experience with TE and mathematics. I designed the course, advocated for its inclusion in my secondary school's program, and am responsible for its design and instruction. I have long believed that TE should be part of a well-rounded education for all students, and not just vocational training. As an engineer who came into education as a second career, I believe that students planning postsecondary studies in engineering could benefit from the skills, knowledge, and habits of mind that TE has to offer. I brought my personal beliefs and my ownership of the course with me to this research study, understanding that this may affect my objectivity as I attempt to study the implementation of *Introduction to Engineering*.

This qualitative case study was limited to the delivery of the *Introduction to Engineering* course over a semester to a class situated in a suburban southern Ontario composite high school. As the teacher of the course, my researcher role was that of a participant observer, and the inherent power imbalance in the student-teacher relationship had to be considered when interpreting the data. Students were apprised and reassured that participation in the research did not comprise any part of their evaluation in the course. By conducting a case study of one class during a single semester, I hoped to gain some deep insight into the integration of TE with academic subjects and its impact on students, along with the potential for engineering as a course in the secondary school curriculum.

Outline of the Remainder of the Document

Chapter Two of this document reviews the literature related to the study of *Introduction to Engineering* and the questions to be explored. The literature review includes an examination of the history of TE and its present-day status. It also investigates the introduction of engineering into the curriculum in other jurisdictions and how TE-as-engineering is touted as a means of raising the status of TE and bringing TE into the educational mainstream. Literature describing cases of the integration of mathematics, science, and technology at the secondary school level are also reviewed.

Chapter Three details the methodology and procedures to be followed in the study. The choice of a qualitative case study research design is justified. The site and participants for the study are described. Data collection and analysis methods are explained, along with the steps that were taken to ensure the reliability and validity of the findings. Finally, the ethical considerations for this study are outlined.

Chapter Four provides a detailed description of the context of the study, including the school, the class environment, the course, and the participants. It also presents the findings of the study and describes the themes that emerged from the data.

Chapter Five discusses the findings of the study in relation to the research questions and the existing literature. The implications of the study for educational practice and educational theory are examined and suggestions for further research are made, based on the findings of the study. Finally, some concluding statements and recommendations are made.

CHAPTER TWO: REVIEW OF THE RELATED LITERATURE

This chapter summarizes the literature reviewed for the study of an *Interdisciplinary Studies: Introduction to Engineering* class over the course of a semester, including the history of TE in North America, its place in the Ontario secondary school curriculum, pre-engineering education in secondary school, IDS in general, and the integration of mathematics, science, and technology at the secondary school level.

A Brief History of Technological Education in North America

Any study which endeavours to explore perceptions of TE must understand its history, which is distinct from that of the school system in general. Modern-day TE has its roots in the industrial revolution of the late 1800s (Lynch, 1997). Skilled workers were needed to meet the demand of rapidly growing industries, and vocational education was seen as a way to meet that demand. However, there was not consensus that the purpose of vocational education should be to supply workers to industry. At the beginning of the 20th century, Charles Prosser and John Dewey debated about the goals of vocational education (Lynch, 1997). Prosser advocated a vocational education system that provided trained workers to industries, while Dewey believed that vocational education should prepare students in "broad problem-solving skills, experimentation, and full participation in democratic processes"(Lynch, 1997, p. 7). The 1917 Smith-Hughes legislation in the United States settled the debate in Prosser's favour, creating a separate vocational education system in the United States (Lynch, 1997).

In Canada, the British North America Act of 1867 gave the provinces responsibility for education. The federal government provided financial support in areas where there was a perceived national need. Early in the 20th century, Dr. John Seath, the

Superintendent of Education for Ontario, studied the industrial and vocational education systems in the United States and Europe. His recommendations became part of the Industrial Education Act of 1911 (Gardner & Hill, 1999a). Throughout the 20th century, federal and provincial legislation provided funding which enabled Ontario to support technical, vocational, and agricultural education, thus fostering the growth of a vocational education system somewhat separate from the academic education system.

Vocational education as manual skills training was entrenched by legislation in the early part of the 20th century. This model has persisted for a century or more in Canada, the US, and abroad. In her review of TE research from 1987 to 1993, Zuga (1997) noted that "the mainstream pattern of the industrial arts curriculum was the manual training curriculum initiated in the 1870s" (p. 203). In British Columbia, "The long history of skill-based practices was entrenched in the *Industrial Education* curriculum guide, published in 1977" (Petrina & Dalley, 2003, p. 123). Hayward (2004) states, "Thus, in the UK, the idea of the vocationalist imperative can be traced from at least the Samuelson Commission on Technical Instruction (1882–84) to the present day"(p. 4).

By the 1980s and 1990s, educators in many English-speaking countries were coming to the realization that a 19th century model for TE would not be suitable for the 21st century (Gardner & Hill, 1999a). The changing world, the changing workplace, and the pace of technological change are often cited as arguments against teaching knowledge or skills that are specific to a particular occupation. Lynch (1997) found that state and national reports on technological curriculum reform commonly recommended an emphasis on cognitive skills and broad technical skills at the secondary level, and the deferral of most occupation-specific training to the postsecondary level. Attention to generic transferable skills, it was argued, will better prepare students for the workplace (Brown, 1998). A focus on broad, transferable skills aligns with the Conference Board of Canada's *Employability Skills 2000+*, which include communication, problem solving, positive attitudes, working with others, and skills in science, technology, and mathematics (Conference Board of Canada, 2000).

In the past few decades, TE curriculum reform has been attempted in Canada, the United States, and abroad. Research suggests that these attempts at reform have met with limited success. Zuga (1997) summarized that the research found little change in the practice of the teaching of technology. Petrina and Dalley (2003) reported that, in British Columbia, the change brought about by TE curriculum reform was superficial. Current practice in British Columbia is essentially that of traditional industrial education, with the names of courses changed to align with the new curriculum.

Since its inception in the industrial revolution, TE has been separated from academic education philosophically and often physically. This study, in part, endeavoured to explore how an integrated mathematics, science, and technology engineering course can help to bring TE into the mainstream of education. It is important to understand the history of TE and to recognize that TE as skills training is deeply ingrained in the culture of TE and highly resistant to change, perhaps because new TE teachers are often coming from a skilled trades culture (Hansen, 1995), and because they are quickly socialized into the existing TE culture (Zuga, 1997).

The Present-day Status of Technological Education in Canada and the US

Technology is ubiquitous in western society, and the role it plays in our lives is ever-increasing. In their publication *Standards for Technological Literacy* (International Technology Educators Association, 2007), the International Technology and Engineering Educators Association defines technological literacy as "the ability to use, manage, assess, and understand technology" (p. 7). A British Columbia Ministry of Education report describes a technologically literate person as someone who "uses tools, materials, systems, and processes in an informed, ethical, and responsible way" (O'Henly, 2001, p. 11). The Ontario TE curriculum (Ministry of Education, 2009) relates students' technological literacy to their "ability to work creatively and competently with technologies that are central to their lives" (p.5).

Curriculum documents tout the importance of technological literacy for all students, yet this is not reflected in secondary school diploma requirements in Canada and the US. In nine Canadian provinces, a student can receive a secondary school diploma without ever taking a TE course (Hill, 2003). In the United States, only 11 states require students to take TE at the secondary school level. The rest of the states either do not require TE, or the decision is left up to local school districts (Meade & Dugger, 2004).

The official TE curriculum has been reformed in a number of Canadian and US jurisdictions over the past two decades in an attempt to broaden the scope of TE and increase the legitimacy of TE as part of the regular curriculum (Gradwell & Welch, 2003; Petrina & Dalley, 2003; Zuga, 1997). However, changes espoused in curriculum documents have not seen widespread implementation in the classroom. In the United

States, the change from industrial arts to technology education has been evolutionary, rather than a wholesale change. The result is a confusing mix of technology education, industrial arts, and vocational training (Akmal, Oaks, & Barker, 2002; Sanders, 2001). Deeply-ingrained skills-training practices have been resistant to change.

TE and its related occupations have low status in the eyes of parents and students (Gardner & Hill, 1999b; Petrina & Dalley, 2003). TE courses in Ontario are promoted as a career pathway to apprenticeships, rather than a field of study that has relevance for all students. College- and university-bound students do not elect to take TE courses, because they do not see them as relevant. Declining enrolment in secondary school programs that focus on vocational training is a worldwide phenomenon. In Ontario, enrolment in TE programs declined almost 47% from 1973 to 1996, while overall secondary school enrolment increased 19% (Smaller, 2000). TE courses may be seen as dead-end courses for drop-outs, less-able students, and students who create disruptions in academic classes (Gradwell & Welch, 2003; Smaller, 2000). More recent data are limited, but it is my belief that this trend has continued through the first decade of the 21st century.

The traditional demographic of TE students has been predominantly white and male, and females and visible minorities have been under-represented in TE classes (Zuga, 1997). The image of TE is that of vocational skills training for white males, rather than a valuable part of a well-rounded education for all students (Lewis, 1999; Petrina & Dalley, 2003; Smaller, 2000; Zuga, 1997). Schools offering general technology programs, as opposed to vocational programs, seem to be making progress in closing the gender gap and enrolling minorities in numbers representative of the population (Sanders, 2001).

Change in TE has been slow. Petrina and Dalley (2003) found that two-thirds of TE teachers in British Columbia continued to follow industrial arts teaching practices in the wake of curriculum reform. Zuga (1997) found that curriculum change in TE was superficial and speculated that beginning TE teachers trained in new curricula were quickly socialized by experienced TE teachers to adopt existing practices. Sometimes the only change is in the names of the programs and courses, rather than in classroom practice. TE is an elective course in most Canadian and American jurisdictions, so TE must come to be valued by a wider range of students if it is to survive and thrive into the 21st century. The present status of TE and students' and parents' perceptions of TE are relevant to this study in that engineering is seen as one way to raise the profile and status of TE.

Engineering: The Future of Technological Education?

TE educators seem to recognize the importance of a more general purpose for TE. In a survey of TE teachers in US high schools and middle schools, the development of problem-solving skills was ranked as the most important purpose for TE, while vocational training was ranked 16th out of 16 purposes surveyed (Sanders, 2001). Another US survey of teachers, teacher educators, and state and regional supervisors identified the place of TE in the whole school curriculum and integration of TE with academic subjects as two of the top five issues facing TE (Wicklein, 2004).

In recent years, there has been a movement in the United States to introduce engineering into the secondary school curriculum. The subject grouping of science, technology, engineering, and mathematics is identified by some as *STEM* at the national level in the US. Reports to congress on STEM issues (Kuenzi, Matthews, & Mangan, 2006), organizations such as the *STEM Education Coalition*, and national initiatives such as *Project Lead the Way* attest to the growing importance of engineering in elementary and secondary education in the United States (Lewis, 2004). American-based organizations such as the International Technology and Engineering Educators Association (ITEEA), the American Society for Engineering Education and the Junior Engineering Technical Society develop engineering curricula for all grade levels from kindergarten to Grade 12 (K-12) and advocate for the inclusion of engineering in the curriculum at all levels. The ITEEA was formerly known as the ITEA, but added the word engineering to its name in 2009. From 1989 to 2003, there was not a single article in the *Journal of Technology Education* that made reference to engineering in its title. From 2004 to 2009, there were 18 articles focusing on aspects of engineering education from K-12.

Engineering is seen as a way of moving TE away from its blue-collar roots and creating a more white-collar image for the field, making the study of technology more palatable to students and parents alike (Lewis, 2004). TE as engineering, it is hoped, will raise the profile and status of TE to the same level as other subject disciplines. Some educators have raised concerns that students' technological literacy will suffer if engineering becomes the focus of TE, but this argument is countered by those who believe that technological literacy will only be enhanced through engineering (Rogers, 2005). Ritz (2006) expressed the opinion that an engineering focus is too narrow and excludes students that may be interested in other career paths. Wicklein (2006) identified five reasons why engineering design should be the focus of TE, including the higher status of engineering in the eyes of the public, the elevation of TE technologically and academically, the framework engineering provides for curriculum organization and integration, and the potential of multiple career pathways for students.

In Canada, education is under provincial jurisdiction, and there is no national organization like ITEEA to advocate for TE or national initiatives like *Project Lead the Way*. In addition, there is little articulation between TE and postsecondary studies (Gradwell & Welch, 2003) and few high school courses directly related to postsecondary studies in engineering. Engineering is still a male-dominated field, so TE-as-engineering may not be an effective means of addressing the gender gap in TE. However, engineering is a first step towards making TE appealing to a wider range of students and introducing TE into the mainstream of the school curriculum (Lewis, 2004; Wicklein, 2006). The infusion of engineering into the K-12 curriculum, as in Massachusetts, for example, will help to make TE more accessible and acceptable to students. This study will help educators to understand students' perceptions and perhaps identify other ways to bring TE to all students, areas requiring further research, or other factors which have yet to be considered.

Interdisciplinary Study

The integration of TE with academic subjects has been identified as one of the most important issues in TE (Foster, 1996; Wicklein, 2004). Engineering, as an interdisciplinary field, offers a possible framework to facilitate this integration (Wicklein, 2006). Mathematics, science, TE, business studies, social sciences, and other subject areas could potentially be integrated under the umbrella of engineering.

Enabling students to see and make connections is the primary purpose of IDS or integrated curriculum (Burns, 1995; Drake & Burns, 2004; Etim, 2005). This may mean connections within or between subject disciplines, connections between school subjects and the work world, or connections between school and students' life experiences. Integrated courses or units are typically problem-centered, focusing on a theme, issue, or problem that has relevance to students. Content is based on curriculum standards or expectations, but transcends subject-specific content to focus on broad cross-disciplinary skills like research, problem solving, and communication.

Terms such as parallel, interdisciplinary, intradisciplinary, crossdisciplinary, multidisciplinary, pluridisciplinary, and transdisciplinary are used in the literature to define models of integration (Burns, 1995; Drake & Burns, 2004; Hayes Jacobs, 1989). These various forms of integration can be placed along a continuum based on the degree of integration and the distinctiveness of discipline boundaries, with simple parallel planning at one extreme and a completely integrated day at the other. Along the integration continuum, the boundaries between subjects become less distinct, and the focus shifts from disciplinary content to cross-disciplinary skills. The Ontario curriculum defines interdisciplinary study as "an approach to learning and knowledge that integrates and benefits from the understanding and application of the approaches of different subjects and disciplines" (Ministry of Education, 2002, p. 4).

Constructivism is often cited as the theoretical foundation for integration. Under constructivist theory, students learn how (techniques, skills, and abilities) in addition to learning that (facts, concepts, and propositions) (Kerka, 1997). The social context of knowledge construction is also important. In contrast to the isolated learning that comprises much of students' experience in school, constructivist theory emphasizes the social context: learning should take place in a community of practice or community of inquiry (Kerka, 1997; Terwel, 1999). Learning as part of a social group, constructivists argue, more closely reflects the reality students will face in the work world. Context is important to constructivist theory: students will construct meaningful knowledge by engaging in authentic learning activities in an environment that approximates a real-world experience as closely as possible (Kerka, 1997; Terwel, 1999).

Proponents of IDS assert that it has many benefits for students, including better preparation for the world outside of school, alignment with cognitive research, reinforcement of cross-curricular skills, facilitation of differentiated instruction, improved student engagement and motivation, improved collaborative and social skills, and higher levels of achievement (Drake & Burns, 2004). In addition, teachers that participate in IDS are typically positive about their experiences, welcoming the opportunity to collaborate with colleagues and be creative in their teaching (Brandt, 1991).

Interdisciplinary study is organized around generic skills that cut across discipline boundaries. Curriculum expectations from a variety of subject disciplines are grouped together in a way that will emphasize interdisciplinary skills such problem solving, research, critical thinking, and communication (Drake & Burns, 2004; Ministry of Education, 2002). Interdisciplinary units or courses focus on a topic, issue, or problem and are student-centered and project-driven. The teacher becomes less of a specialist delivering content and more of a facilitator. By grouping curriculum expectations together, explicit connections are made between disciplines. Interdisciplinary curriculum may connect two closely related subjects, such as mathematics and science, or may encompass a broader range of disciplines. *Interdisciplinary Studies: Introduction to Engineering* used an interdisciplinary approach which enabled students to use cross-disciplinary skills such as research, problem solving, designing, modeling, and communication, in conjunction with disciplinary knowledge and skills, to synthesize solutions to design problems.

Cases of Interdisciplinary Study in Secondary School

Interdisciplinary study can be found at all levels of education, involving a wide spectrum of subject disciplines. Examples of IDS at the elementary or middle school level are the most common in the literature (Hinde, 2005; Post, Ellis, Humphreys, & Buggey, 1997; Ronis, 2008). Cases at the secondary school level frequently focus on the integration of mathematics and science in vocational courses (Brown, 1998; Fitzsimons, 2001; Gibbs, 2006; Olds & Lightner, 1995; Stern, Dayton, Paik, Weisberg, & Evans, 1988; Zinzer & Poledink, 2005). The *Introduction to Engineering* course that was investigated in this study is a university preparation course most likely to attract university- and college-bound students, rather than those interested in vocational training. Many studies of IDS are not directly relevant to this study. For example, some of the studies focused on aspects such as the impact of IDS on student achievement (Dugger & Meier, 1994) or the infrastructure necessary to support IDS (Spies, 2001). In other cases, the term technology meant ICT (Fitzsimons, 2001) or was not clearly defined but seemed to be synonymous with computers (Geraedts, Boersma, & Eijkelhof, 2006). Studies that involved mathematics, science, and technology at the secondary school level and served a general purpose rather than a vocational purpose were sparse in the literature. These studies are summarized below and provide an overview of the integration of mathematics, science, and technology that is relevant to the study of *Introduction to Engineering*.

Wicklein and Schell (1995) describe integrated mathematics, science, and technology programs developed at four US high schools, one in each of Colorado, Missouri, Nebraska, and Oklahoma. The integration team at each school was comprised of teachers of mathematics, science, and technology, plus an administrator and a resource team. The creation of the IDS programs was initiated by the researchers, but each school took a different approach to the integrated project.

The Missouri high school integrated technology into a biology course, with support from the mathematics teacher. In this case technology meant computers or ICT. The teachers took a problem-solving approach in the course, and students were encouraged to access other instructional areas. However, the teachers found that some students had difficulty overcoming the subject boundaries that had become engrained in their minds. Because the technology component of the course was limited to computer technology, its relevance to *Introduction to Engineering* is limited.

In Nebraska, an established *Principles of Technology* course was used to integrate mathematics, science, and technology. A team teaching approach was used, and the course was intended for at-risk Grade 9 students. *Introduction to Engineering* is intended for university-bound senior students, so the relevance of the Nebraska case is also limited. The Oklahoma high school also used an established *Principles of Technology* course, rotating teachers for specific instructional units.

The Colorado case is the most relevant to the *Introduction to Engineering* course that was the subject of this study. Each of the mathematics, science, and technology teachers wrote an integrated course in his area of expertise. The mathematics and science teachers revised existing algebra and applied physics courses, while the technology teacher developed a new *Introduction to Engineering* course. This course syllabus is most relevant to this study. The objectives of the Colorado *Introduction to Engineering* course were to:

- Interpret mathematics and science principles;
- Apply technology to solve for natural and man-made problems;
- Synthesize mathematics, science, and technological techniques to aid in problem resolution;
- Evaluate engineering solutions for appropriateness;
- Appreciate the broad spectrum of knowledge and application required in engineering;
- Accept responsibility for self-motivation and self-learning of mathematics, science, and technology in the realm of engineering (p. 67).

The Colorado *Introduction to Engineering* course was designed as an interdisciplinary, problem-based course. Its objectives were used as one reference in the development of the framework for the *Introduction to Engineering* course under investigation in this study.

Verner, Waks, and Kohlburg (1997) presented a case of an interdisciplinary robotics course in an Israeli high school. This case has many parallels to the design and implementation of the *Introduction to Engineering* course that was the focus of this study. TE is not compulsory in the Israeli high school system, and academic students typically do not take technology courses. The technology educators in the case study believed that technology courses should be available for all students, recognizing that technology education courses would have to be revised to meet the needs of academic students.

Like *Introduction to Engineering*, the interdisciplinary robotics course was an optional course designed for academic students who have likely had no exposure to TE courses. The course was activity-based, focused on technological systems and the design process, involved teamwork and creative problem solving, and provided students opportunities to apply knowledge and skills acquired in mathematics and science courses through performance tasks. Assessment was based on projects and portfolios, rather than written tests and exams.

Verner et al. (1997) gathered student feedback in order to assess the influence of the interdisciplinary course. Students' responses to the course were very positive, giving high marks for the content of the course and the creativity involved. Participation in the course helped a significant percentage of students overcome their fear of technology and changed some students' views of technology. This case provided encouragement that an integrated mathematics, science, and technology course can be made relevant for academically inclined students who may not otherwise be exposed to TE.

Shelly, Cannaday, and Weddle (1997) describe the development and implementation of *Product Design Engineering*, an optional multidisciplinary high school course taught by a team consisting of a professional engineer, a science teacher, and a retired technology teacher. The course focused on identifying design problems and building and testing solutions. It also addressed the engineering profession and engineering problem-solving processes. The instructional approach was nontraditional, with the teacher acting as a facilitator. Shelly et al. described what the students did in the course as evidence of reformed teaching and learning, including report writing, making presentations to panels of professionals, designing and building, product testing, computer modeling, making interdisciplinary connections, and thinking and acting like engineers. The researchers observed that students were excited and enthusiastic about mathematics, science, technology, and engineering. Because *Product Design Engineering* was a new course, the researchers sought to understand what the students saw as risks when selecting an elective such as this. Among the potential risks from the students' perspective were: the fear that no right answers exist for design problems, the intimidation of hands-on project construction in the shop, the negotiating and social skills required for group work, and the lack of experience in tackling an authentic real-world problem. Since the *Introduction to Engineering* course that was the subject of this study was a new elective course, students' concerns when choosing an elective are relevant to the implementation and future success of the course.

The case studies summarized here provide an overview of what has been done elsewhere and a broad framework for designing a course that integrates mathematics, science, and technology. Some of the research also provides insight into students' attitudes both before and after participating in an integrated course. These case studies helped to provide direction in this study of the implementation of *Introduction to Engineering.*

Although some of these case studies provide frameworks for the courses they describe, more detailed outlines and examples of secondary school engineering curricula were required to develop the units of study for *Introduction to Engineering.* Childress and Rhodes (2008) conducted a survey of practicing engineers and engineering educators to determine which engineering outcomes were considered most important for grade 9 to 12 students considering postsecondary studies in engineering. Groupings of outcomes were ranked in order of importance. These groupings were, in order: (a) engineering design, (b) application of engineering design, (c) engineering analysis, (d) engineering and human values, (e) engineering communication, (f) engineering science, and (g) emerging fields of engineering. These groupings, and the specific outcomes within the groups, served as a guide in designing *Introduction to Engineering.*

The ITEEA publishes curriculum materials to support the infusion of engineering into the secondary school curriculum. *Engineering Design: A Standards-Based High School Model Course Guide* (International Technology Educators Association, 2004), outlines a comprehensive secondary school engineering course, complete with a scope and sequence, unit plans, teacher preparation materials, suggested projects, assessment tools, and lists of resources. This guide proved invaluable for organizing the course and providing ideas for projects and assignments. The second edition of the course guide, issued on CD-ROM, proved to be an equally valuable resource (International Technology Educators Association, 2008).

An Introduction to Engineering (Onwubiko, 1997) is a textbook designed to be used with a first-year university engineering course and is intended to introduce university freshmen to the profession of engineering. Although much of the course material overlaps with the ITEEA curriculum materials, Onwubiko's text provides more in-depth information on the history of engineering, distinct engineering disciplines, and the practice of professional engineering. This resource reinforced and complemented the

ITEEA resources and contributed to the design of *Interdisciplinary Studies: Introduction to Engineering*.

In addition the resources described above, I drew on my experience as an engineer and my experience teaching construction technology, technological design, and mathematics to enhance the design of the course. This included the inclusion of three-dimensional parametric modeling computer assisted design (CAD) software, design/build projects that required the use of available shop facilities, and the adaptation of existing technological design projects to explicitly include mathematics, physics, and engineering analysis.

Summary

Technological education has its roots in the vocational education system established during the industrial revolution of the late 19th century to provide skilled workers to industry. TE developed as a separate system parallel to mainstream education, a division that is still apparent today. TE's long history, coupled with the skilled trades' experience of many TE teachers, has made it highly resistant to attempts at curriculum reform. TE as manual skills training for specific occupations persists into the 21st century. TE suffers from low status in the eyes of parents and students. Its courses and career pathways are not as highly valued as those of academic subject disciplines. The perception of TE continues to be that of manual skills training for white males. Despite an increasingly technological world, enrolment in TE in Canada, the US, and abroad continues to decline.

Engineering is promoted by some as a way to bring TE into the mainstream of education, exposing a broader spectrum of students to TE and raising its status and profile. Movements such as *Project Lead the Way*, subject groupings such as *STEM,* and educator groups such as ITEEA are promoting the inclusion of engineering in the K-12 curriculum. Prominent writers and researchers in the field tout engineering as a means of revitalizing TE while better meeting the needs of all students.

Interdisciplinary study takes many forms. Definitions found in the literature are consistent with those found in the Ontario curriculum. *Introduction to Engineering* follows an interdisciplinary model as defined in the literature: students draw on knowledge and skills from mathematics, physics, and technological design to solve engineering problems while developing cross-disciplinary skills such as research, analysis, modeling, and communication. This study uses themes emerging from the review of the literature in exploring the implementation of *Introduction to Engineering*, including addressing the lack of engineering in the Ontario curriculum, fostering a more general purpose for TE, raising the status of TE, and participation in integrated curriculum.

The following chapter will detail the methodology and procedures to be followed in the study. The choice of a qualitative case study research design will be justified. The site and participants for the study will be described. Data collection and analysis methods will be explained, along with the steps that will be taken to ensure the reliability and validity of the findings. Finally, the ethical considerations for this study will be outlined.

CHAPTER THREE: METHODOLOGY

Interdisciplinary Studies: Introduction to Engineering was a Grade 12 university preparation course that integrated curriculum expectations from mathematics, physics, and technological design under the umbrella of engineering. The purpose of this study was to explore the implementation of *Introduction to Engineering* and students' experiences in the course. The study was a qualitative case study of a single class over the course of a semester. It focused on the use of engineering as an interdisciplinary organizing theme, the relevance of the study of engineering for secondary school students, and students' perceptions of interdisciplinary study in mathematics, science, and technology.

Research Design

Research in technological education has been limited relative to that in other subject disciplines, such as English, mathematics, or science (Lewis, 1999; Zuga, 1997). Most TE research has been quantitative, focusing on existing practices and the status of the TE curriculum (Petrina, 1998; Zuga, 1997). More recently, TE researchers have been encouraged to explore qualitative methods as a means of broadening the scope of TE research and exploring new directions (Hoepfl, 1997; Lewis, 1999). Hoepfl presented a primer on qualitative research to encourage TE researchers to consider qualitative methods. Lewis called for more classroom-based qualitative studies that extend over meaningful periods of time.

Qualitative research may be used to gain understanding of the factors influencing a situation or to identify issues requiring further study (Creswell, 2008; Hancock & Algozzine, 2006). Where quantitative research focuses upon quasi-experimental and correlational studies using numerical data, qualitative research seeks an understanding of phenomenon as they happen using descriptive data (Stake, 1995). Given that TE research and research on the integration of TE with academic subjects are lacking, the study of *Introduction to Engineering* lent itself to exploratory qualitative methods. An understanding of the implementation of the course, especially from students' perspectives, will help to inform future changes to the course and perhaps suggest directions for further research.

A case is a contemporary, complex, functioning, real-life phenomenon bounded by space and time (Creswell, 2008; Stake, 1995; Yin, 2009). A case may be a program, an event, an activity, a process, individuals, or a group. Yin defines case study as "an empirical enquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 18). A case study is appropriate when a phenomenon is complex or when there are many variables or the variables are unknown.

This case study involved a single class of *Interdisciplinary Studies: Introduction to Engineering* over the course of one semester within a suburban secondary school in a large school board in southern Ontario. As an exploratory study of a phenomenon bounded by space and time and limited to the individuals in the course, a qualitative case study was a suitable research method for this study. Examining *Introduction to Engineering* within its context was essential to understanding students' experiences and the place of the course in the curriculum.

Case study researchers endeavour to describe phenomena as accurately as possible, retaining its meaningful characteristics for the reader (Yin, 2009). Typically, case study researchers have little or no control over the events they are studying. Although informal manipulation of events may occur, the investigator is not administering a treatment to determine its effects. This study sought to understand the experience of an interdisciplinary course in mathematics, science, and technology for the students involved. As the teacher of the course, I manipulated events within the course (e.g., activity design, evaluating assignments), but the intent of the study was to explore the implementation of the course in a naturalistic manner with limited interference from a researcher. As suggested by Hancock and Algozzine (2006), an exploratory study of *Introduction to Engineering* may influence policy, identify variables, or suggest directions for future study.

Site and Participant Selection

The selection of the case in this study was predetermined by my role as the designer and teacher of *Interdisciplinary Studies: Introduction to Engineering*. This may be considered an intrinsic case, or one in which the case itself is unusual or of particular interest, as opposed to an instrumental case which is studied to gain understanding of some broader issue (Stake, 1995). *Introduction to Engineering* was, in my experience, unique in Ontario. As the teacher of *Introduction to Engineering*, I had access to participants and activities that would not have been possible with the investigation of another TE case. This full-time insider access and the unique nature of the course justified the pre-selection of this particular case, despite my dual role as teacher and researcher.

Curriculum Context

Silver Maple High School (a pseudonym) is a composite high school located in an affluent suburban community in southern Ontario. It has an ethnically diverse population of approximately 1200 students. The school offers all required Grade 11 and 12 university and college preparation courses, some open courses, and a few workplace preparation courses. In addition to the required courses, the school offers a wide range of optional courses including physical education, the arts, business studies, and technological education. *Interdisciplinary Studies: Introduction to Engineering* was a Grade 12 university preparation optional course.

The *Introduction to Engineering* class was held in the technological design facility, which was comprised of a drafting room measuring approximately 40 feet long by 26 feet wide, with a 10-foot high ceiling. There were 24 drafting tables in the room: 10 with horizontal surfaces and 14 with surfaces tilted at an angle. Manual drafting tools such as T-squares, set squares, and metric and imperial scales were available for use. In addition, the room had an interactive white board connected to a laptop with access to the school network, the internet, standard board-licensed software, and the CAD software used in the technological design program.

In the classroom, there were some hand tools, such as hammers, screwdrivers, saws, and soldering irons available for students. However, the room was located in the technological education wing of the school, with easy access to the construction shop and manufacturing shop. If necessary, students could easily go to these rooms to obtain other tools or use equipment if required.

Adjoining the drafting room was a computer lab with 24 workstations. The rooms were connected by a door which had an adjacent window, creating a line of sight from one room to the other. In addition to word processing, spreadsheet, presentation, internet browsing, and other common software, computer assisted design software was installed on the computers.

The researcher was also the developer and teacher of *Introduction to Engineering*. I hold a Bachelor of Science in Engineering degree and worked as a professional engineer in the construction industry prior to becoming a teacher. My teaching qualifications are in construction technology and technological design, but I have taught mathematics in many of my 17 years of teaching. I designed *Introduction to Engineering* as part of an assignment for a Master of Education course and lobbied my school's leadership team for its inclusion in the school program. I was required to balance the roles of researcher and teacher throughout the semester.

The course ran from September 2009 to January 2010, with 12 students enrolled. These 12 students were invited to be participants in the study, and 11 of the 12 students, 10 male and one female, opted to participate. This study endeavoured to describe students' experiences in and perceptions of the course. The study also explored the field of engineering as an organizing theme for integrating mathematics, science, and technology within the secondary school curriculum.

Data Collection

In case study research, the researcher becomes the primary instrument of data collection (Hancock & Algozzine, 2006). Data are collected from multiple sources of evidence, such as observations, interviews, open-ended questionnaires, documents, artefacts, photographs, and video and audio recordings (Creswell, 2008). There are no set procedures or routines for conducting case study research, making case study research difficult (Yin, 2009). A case study researcher requires a variety of skills including the ability to ask good questions, good listening skills, reflexivity, adaptability and flexibility, attention to detail, and a firm grasp of the issues associated with the case (Creswell, 2008; Stake, 1995; Yin, 2009). In addition, the case study researcher must be able to collect data in multiple forms. As a novice researcher, this required skill set is somewhat daunting. A plan or protocol for organizing the case study will aid in the collection of data and will help to keep the research focused (Stake, 1995; Yin, 2009). Much of the information suggested for inclusion in a case study protocol, such as an overview of the case, the purpose of the study, sources of data, ethical considerations, and research questions, are included.

As the teacher of *Introduction to Engineering*, I collected data as a participant observer. This had advantages in access to activities and individuals, a perspective from inside the case, and the ability to manipulate minor events within the case. It also provided the opportunity to record events as they happened in their natural context (Creswell, 2008; Yin 2009). However, bias is a major problem in the participant observer role, and I needed to be aware of my preconceived ideas about the case and be open to contrary evidence or outliers in the data.

Because I was the teacher of the course, it was sometimes difficult to record my observations of events as they occurred during class. I established a routine of jotting down quick anecdotal notes as memory aids during class, and recording my observations in more detail as soon as possible after class, while the events were still current in my mind. During the study, my preparation period immediately followed the *Introduction to Engineering* class, which enabled me to record thoughts and observations immediately after the class.

An observation protocol was used to organize data collected through observation (see Appendix A). The protocol was used not only to record descriptions of settings, events, and individuals, but also to record the researcher's reflections on the meaning of those observations. The observational protocol was used to describe students, their activities, my interactions with students, and their interactions with each other. The observational data provided evidence of students' experiences in the course. Data about students' perceptions were gleaned through students' conversations with each other and with me.

Observations of students as they used mathematics, science, and technology to solve engineering problems provided data that informed the research question about engineering as an interdisciplinary theme. Further information about students' integration of mathematics, science, and technology and their experiences with interdisciplinary study were gathered through the analysis of student work, such as physical products, computer models, drawings, presentations, and design notes. This is a common method of data collection in studies addressing student design activities (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; MacDonald & Gustafson, 2004; Verner & Hershko, 2003). Samples representative of student work were collected after the completion of each project in the course (see Appendix B).

Another method of collecting data on students' experiences and perceptions of *Introduction to Engineering* was through the use of confidential open-ended questionnaires (see Appendix C). A pilot questionnaire was administered to a previous class of *Introduction to Engineering* in June 2008 for the purpose of testing the questionnaire and thereby increasing its validity. Information from this questionnaire resulted in modifications to the questionnaire and the addition of questionnaires at the beginning and middle of the semester.

The questionnaires were administered at the beginning of the semester in September, near the middle of the semester in November, and toward the end of the course in January. Students were asked to reflect on their experiences in *Introduction to Engineering,* their perceptions of interdisciplinary study, TE, and engineering, and to share their reasons for opting to take the course. After the course had concluded and final marks had been submitted, a focus group was held with six of the students from the course. They were asked to elaborate on information provided in the questionnaires, add any new perspectives, and to provide a retrospective of their experiences in the course.

Data Analysis

Most of the data in this study were in the form of text generated from observational notes and student questionnaires. Prior to analysis, data were organized by time and type: September, November, and January questionnaires, the researcher's observational anecdotal notes, artefacts representative of students' work, and the researcher's notes from the focus group discussion. Handwritten notes and completed observational protocols were filed chronologically. Representative samples of student work were filed by project, physically and electronically. Creating a database for organizing and collecting data increases the reliability of the case by enabling the data to be examined by others (Yin, 2009).

Qualitative data are analyzed through a process of coding (Creswell, 2008). Student responses to each questionnaire were transcribed into an electronic copy of the questionnaire. Student responses to each question were typed verbatim into the electronic copy, collecting together all responses to each question. Observational data and data from the focus group interview were also transcribed into electronic format.

Data analysis was conducted by inductive analysis to generate themes from the data. After an initial read-through of the collected responses to get a general sense of the data, text segments in questionnaire responses, observational notes, and focus group notes were coded according to their meaning. Each text segment was colour-coded to indicate its source: the September questionnaire, the November questionnaire, the January questionnaire, observation notes, or focus group notes. As themes emerged from the data, the colour-coded text segments were classified under one of the themes. Codes that were similar, overlapping, or redundant were aggregated into a single code, but tallied to monitor frequency of occurrence. Similar codes were grouped together and under common themes.

The initial analysis classified the codes under the themes: (a) choosing electives, (b) engineers and engineering, (c) interdisciplinarity, (d) approach to learning, (e) cognition, and (f) affective domain. As the analysis progressed, it became apparent that the data could be better categorized under themes grounded in interdisciplinary study. Coded text segments were reanalysed and categorized under the themes (a) connecting to the world outside of secondary school, (b) connecting subject disciplines, (c) project-based learning, and (d) student engagement and affective outcomes.

These themes are related to benefits of interdisciplinary study as espoused by its proponents. The data aggregated under these themes addressed both research questions, and the themes were often connected or overlapping. The themes connect to the literature relevant to the case study, such as the place of TE in the curriculum, the study of engineering in secondary school, and interdisciplinary study. While expository narrative writing is the most common way of presenting findings in qualitative research, tables, figures, and diagrams may also be used.

Reliability and Validity

Reliability is more commonly associated with quantitative studies, but reliability in a case study means that the procedures of a case study can be repeated with a similar result. According to Yin (2009), the reliability of a case study can be increased by using a case study protocol that includes an overview of the study, methodology for the study, and the case study questions. This study has a structure similar to that of Yin's case study protocol, and this helped to increase the reliability of the study by providing procedures that another researcher could follow if he or she wished to repeat the study.

Qualitative researchers validate findings and determine credibility through triangulation or member checking (Creswell, 2008). Data triangulation means that data from several sources support the same finding. This may mean triangulation using different forms of data or data from different individuals. Data in this study were collected through observations and reflections, questionnaires, and artefacts, which were triangulated to enhance the credibility of the findings (Hoepfl, 1997). Other case studies in TE have collected data using field notes, teachers' journals, student projects and portfolios, and assessment items (Doppelt et al., 2008; Norton, 2007; Verner & Hershko, 2003).

Member checking means that the researcher asks participants to confirm the accuracy of their accounts. In her study of the mathematical modeling of structural engineers, Gainsburg (2006) confirmed the written accounts of her observations with the engineers that were the subjects of the study. It seems that classroom-based researchers often do not perform member checks with students, especially in studies that involve elementary-aged children (Doppelt et al., 2008; Koch & Feingold, 2006; Macdonald & Gustafson, 2004). Member checks were performed in this case by periodically reviewing my accounting of events with the students involved. Following the conclusion of the course, students participated in a focus group to provide additional information or clarification regarding their experiences in and perceptions of the course. In June 2010, students were given a written summary of information gleaned from the questionnaires, and asked to anonymously confirm, clarify, or contradict my interpretations of the data.

I am the designer and teacher of *Introduction to Engineering*, and want to see the course succeed as a viable part of the school curriculum. As well, I am a proponent of interdisciplinary study. I believe that the study of engineering in secondary school is lacking and could be a way of revitalizing TE, making it relevant for a broader spectrum of students. In my research, I looked for evidence to support these propositions, but also had to be receptive to evidence that might contradict them. As the teacher of *Introduction to Engineering*, I was immersed in its day-to-day activities, which sometimes made it difficult to make and record observations of the events in the class. As a researcher, I attempted to step back from that role to record and examine evidence from a different perspective. I enlisted the help of a "critical friend" (Costa & Kallick, 1993) to review my observational notes and data analysis, and to offer a critical analysis of my reflections. This critical friend is an experienced physics teacher and a fellow Master of Education student who has an understanding of the research process and has been cognizant of the development of *Introduction to Engineering* since its inception.

In case studies of the integration of mathematics, science, and technology, it is not unusual for the researchers to have some role in the initiation, implementation, or instruction of the program under study (Shelley, Cannaday, & Weddle, 1997; Verner et al., 1997; Wicklein & Schell, 1995; Zinser & Poledink, 2005). Although case study researchers are often participant observers with some attachment to the case, it is important to acknowledge this role and attempt to mitigate any bias that this may bring in the collection and analysis of data (Hancock & Algozzine, 2006).

Ethical Considerations

There is an inherent power imbalance in the student-teacher relationship. Since I taught the *Introduction to Engineering* class that is the subject of this case study, steps were taken to ensure that students were not intimidated by this power imbalance in ways that would affect the outcome of the study. The letter of invitation made it clear that participation in the study did not comprise any part of students' evaluation in the course, and that students could opt not to participate in the study without fear of penalty or reprisal. In the event that a student believed he or she was being treated inequitably due to non-participation in the study, the letter of invitation instructed the student to express concerns to the department head or the school administration.

Consent was obtained through a letter of invitation and a consent form which were distributed and collected by a school administrator who was aware of the importance of confidentiality and anonymity in educational research. The administrator had a class list indicating which students had returned the consent form. Questionnaires were administered by the school vice-principal and were anonymous. Completed questionnaires were kept in a sealed envelope in the vice-principal's office until marks for the course had been submitted. This was to ensure students that their responses on the questionnaire would not affect their evaluation in the course.

In the letter of invitation and consent form, students and their parents were informed of students' right to withdraw from the study at any time. A student could have expressed his or her desire to withdraw verbally to the teacher (principal investigator), technological education department head, principal, or vice-principal. A participant's data would not have been used in the study if he or she chose to withdraw. The withdrawal would have had no effect on the teacher's assessment and evaluation of the student's coursework.

Only the principal investigator and supervisor had access to the data collected. All information related to this study was held in the principal investigator's home in a locked file cabinet. Electronic data were entered into a computer that had secured access and was only available to the researcher and the supervisor. After a 2-year interval, all documentation including questionnaires and data analysis documents will be shredded at Brock University's Hamilton campus. All electronic versions and files relating to this study will be deleted.

Students will be provided with an executive summary of the final report detailing the results of the study. Since many of the students may have graduated by the time the report is prepared, a copy will be made available to the principal so he can distribute the report, and the report will be kept in the technological education course of study file, for future reference and dissemination.

This study obtained clearance from Brock University's Research Ethics Board on August 31, 2009 (see Appendix D). Clearance was received from the school board's Research Advisory Committee in June 2009.

Summary

The purpose of this study was to explore students' experiences in *Interdisciplinary Studies: Introduction to Engineering*, and to explore engineering as an organizing theme for the integration of mathematics, science, and technology. It was a qualitative case study, with the researcher in the role of participant observer as well as the designer and teacher of the course. Data were collected through observation and reflection, artefacts, and questionnaires. Data analysis was conducted through coding of textual data to establish themes. Findings were validated through triangulation of data and through member checks.

As the designer and teacher of the course being investigated, I had to maintain an awareness of my own beliefs and preconceptions, especially when reflecting on and interpreting the data. I had to keep an open mind to data that may have contradicted my personal beliefs. The inherent power imbalance in the student-teacher relationship had to be mitigated to ensure that students provided truthful and accurate information and to ensure that students did not feel that nonparticipation in the study would negatively affect their evaluation in the course.

CHAPTER FOUR: PRESENTATION OF RESULTS

This chapter will present details of the findings of this study. The purposes of this study were to explore students' experiences in and perceptions of *Interdisciplinary Studies: Introduction to Engineering* and to investigate the viability of engineering as an organizing theme for the integration of mathematics, science and technology in secondary school. The participants in the study were Grade 12 students enrolled in *Introduction to Engineering*, a Grade 12 optional university preparation course offered under Ontario's *Interdisciplinary Studies* curriculum. As the designer and teacher of the course, the researcher was in the role of participant observer. Succinctly, the study was a qualitative case study of a single class of *Introduction to Engineering* over the course of a semester, from September 2009 to January 2010.

The Context of the Study

Since this study involved a single class of *Introduction to Engineering* over the course of a semester, its context is important to the study. This includes the course and its associated projects, the physical environment of the classroom, and the participants in the study. The following sections will describe *Introduction to Engineering* as a course, its major projects, and provide a profile of the students who were the participants in this study.

The Course

Introduction to Engineering integrated selected expectations from mathematics, physics, and technological design. Although prior or concurrent enrolment in mathematics, physics, and technological design were recommended for students opting to take *Introduction to Engineering*, they were not prerequisites. The course was comprised of a series of projects, interspersed with minor assignments on engineering history, law, and ethics as well as occasional guest speakers. The course outline for *Introduction to Engineering* is provided in Appendix E.

Introduction to Engineering was usually an unstructured class. On a typical day, students would come into the class and set to work on the current project. Projects were lengthy, taking weeks to complete. The open-ended nature of the projects meant that the necessary steps for completing the projects were not prescribed by the teacher. Although some whole-class instruction was required, usually to introduce and outline projects, the teacher's role was more often that of facilitator. Depending on their tasks on a particular day, students would be distributed over the drafting room, the adjacent computer, or one of the shops. During most classes, in my teaching capacity, I circulated among the students, making suggestions, providing individual instruction as necessary, and helping students solve the many smaller problems that comprised the larger projects. The three projects that comprised the bulk of *Introduction to Engineering* are described below.

The first major student project was to design and construct a stable, comfortable, aesthetically appealing chair capable of supporting 200 pounds using only corrugated cardboard and glue (see Appendix F). In the interest of efficient use of material, students had to minimize the amount of cardboard used, while still meeting the other project criteria. Students were assigned to a group of three by the teacher, based on prior or concurrent credits in mathematics, physics, and technological design. This was in order to ensure that each group had a balance of skills and knowledge from the three subject areas. Each member of a group assumed one of three roles: product design engineer, ergonomics engineer, or structural engineer.

The second major project was to construct, assemble, and animate a three-dimensional computer model of a mechanism from a given set of working drawings (see Appendix B).The mechanisms assigned to students converted linear motion to rotary motion or vice versa, such as a cam and follower or a crankshaft and piston. Autodesk Inventor three-dimensional parametric modelling software was used to construct the models, generate technical drawings, and analyse the models' sinusoidal motion.

The third and final major project was to design and construct a Rube Goldberg machine (see Appendix F). Goldberg machines complete a simple task in a complicated, indirect way. The name is derived from cartoonist Rube Goldberg who was trained as an engineer, but became famous for drawing complicated, fantastical devices (Rube Goldberg Inc., 2010). Goldberg competitions are held each year in the United States for university and secondary school students.

The criteria for this project were derived from the rules for these competitions. Since the *Introduction to Engineering* class that was the subject of this study was a small class of only 12 students, I proposed to the class that they construct a single, large, and a minimum 20-step Goldberg machine aligned with the criteria of a high school Goldberg competition (Rube Goldberg Inc., 2010). The class was receptive to the idea of working as a class to create a competition-scale Goldberg machine.

Students' Academic Background

Eleven Grade 12 students participated in the study. Because the prerequisite for a Grade 12 university preparation interdisciplinary course is any Grade 11 university or University/College preparation course, the students came into *Introduction to Engineering* with a wide range of knowledge and skills in mathematics, physics, and technological design, as shown in Table 1. Although only seven of 11 students had taken a technological design course specifically, 10 of the 11 students had taken at least one technological education course. Only one student had not taken any technological education courses.

Facets of Interdisciplinary Study

Data collected during the study were in the form of students' written responses to questionnaires (see Appendix C), the researcher's observational notes and personal communication with the students, artefacts representative of students' work, and researcher's notes taken during a focus group interview with students approximately one month after the conclusion of the course. Questionnaires were administered on the first day of the course in September 2009, near mid-semester in November 2009, and near the end of the course in January 2010. A member check was performed in June 2010 by providing participants with a summary of questionnaire responses and asking them to confirm, contradict, or add to the researcher's interpretations of their responses.

Student responses to each questionnaire were transcribed verbatim into electronic copies of the questionnaires, collecting together all responses to each question. Observational data and data from the focus group were also transcribed into electronic format. Data analysis was conducted by inductive analysis to generate themes from the data. The themes that emerged from the data were aligned with topics frequently found associated with interdisciplinary study: (a) connecting to the world outside of secondary

Table 1

Courses Taken Prior to or Concurrent With Introduction to Engineering

	Grade 11			Grade 12			None
Course Level	U	U/C	C	U	U/C	C	
Mathematics	8	2	1	8		1	
Physics	8			4			3
Technological Design		7			2		4

Note. U = University preparation; U/C = University/College preparation; C = College preparation school, (b) connecting subject disciplines, (c) project-based learning, and (d) student engagement and affective outcomes. These themes are related to benefits of interdisciplinary study as espoused by its proponents. The data aggregated under these themes addressed both research questions, and the themes were often connected or overlapping.

Connecting to the World Outside of Secondary School

One of the impetuses for the development of *Introduction to Engineering* was to improve students' understanding of the profession and practice of engineering. Preparation for the future was indicated by six of 11 study participants as one of the factors they consider when choosing elective courses. In some cases, this meant that students consider electives that specifically relate to their intended postsecondary studies, while in other cases, students reported that they choose electives that will provide knowledge and skills that may be useful either in postsecondary destinations or in their day-to-day lives.

In regard to choosing *Introduction to Engineering* specifically, seven of the 11 students (64%) said that assessing engineering as a career choice or acquiring some engineering knowledge and skills before entering a postsecondary program was their primary reason for opting to take the course. One student, knowing that I was an engineer before becoming a teacher, stated "I took this course hoping to learn from an actual engineer, and not learn from books and readings" (student response, September questionnaire). Those students not intending on pursuing postsecondary studies in engineering were attracted to the design/build nature of the course, and thought it would be interesting, and were hoping to acquire useful transferable skills.

As part of the initial September questionnaire, students were asked to give their definition of engineering. Nine of the 11 responses (82%) reflected how engineering connects to the world at large and to their day-to-day lives through the design, construction, manufacture, innovation, and improvement of the products, services and infrastructure they use everyday. Students recognized that engineering solves problems, applies knowledge to practical ends, and strives to make the world a better place. As one student remarked: "(Engineering is) using math, sciences and tech design to solve and build a solution to a problem. The field of imagination and creation; to help facilitate the world" (student response, September questionnaire).

Over the course of the semester, the class welcomed several guest speakers and went on a field trip to visit a multinational, multidisciplinary consulting engineering firm. The guest speakers were: an engineer from Atomic Energy of Canada Limited who specializes in human factors engineering; a recent mechanical engineering graduate employed by a local consulting engineering firm; and, a representative from Professional Engineers Ontario who addressed engineering ethics and the role of the association in the governance of engineering in Ontario.

Observational data recorded during guest speakers' presentations indicated that students were engaged by the engineers' presentations and asked relevant and thoughtful questions. My notes taken during class discussions the day after each presentation and notes of conversations with individual students showed that students welcomed the opportunity to listen to and speak with working engineers. The recent mechanical engineering graduate shared his university experiences, and students were so engaged that time elapsed before they could ask all of their questions. Overall, students were very positive about the guest speakers and indicated that making this connection to working engineers was a valuable part of the course.

Furthermore, observational data were collected during a field trip to a consulting engineering firm. I recorded my reflections about the field trip upon our return to the school, based on my observations of the students. The field trip provided students the opportunity to see a working engineering office. They were able to meet many of the firm's employees, and hear about their roles in the company. This included not just different types of engineers, but also architects, scientists, and technicians. Students participated in a networking luncheon with young professionals from the firm and were able to ask them questions about their experiences in university and at work. They had the opportunity to attend a CAD software demonstration, participate in a problem-solving exercise, and tour the offices of the engineering firm. I observed that students made the connection between the engineering firm's work and their coursework in *Introduction to Engineering* as they recognized familiar software and similar design processes.

The following day, we had a class discussion regarding the field trip. The students felt that the experience was worthwhile and gave them insight into the day-to-day work of engineers. I observed that students were enthused during the field trip. Two students had been unable to attend the field trip and afterwards, some of the students that attended described the trip to their classmates with comments like, "You should've come! It was sick!" (personal communication, October 22, 2009).

On the mid-semester questionnaire, eight of 10 students (80%) indicated that their understanding of engineering had improved from their participation in the course. One student commented "My understanding of engineering has been greatly improved. I have a better sense of what engineering is" while another responded "I feel I have learned more about what engineering would be like" (student responses, November questionnaire).

Students were asked to define engineering on both the initial and final questionnaires. The September responses showed that students had some understanding of engineering coming into the course, but their definitions were somewhat vague, such as "Engineering is designing and figuring out how to build a structure, I think" (student response, September questionnaire). Responses on the January questionnaire were more precise, with students more often including problem solving and engineering's use of mathematics and science in their definitions: "(Engineering) is a study of combination of math, science and other things that's used to solve practical problems" (student response, January questionnaire).

In general, students indicated that the course improved or reinforced their understanding of engineering. "It [*Introduction to Engineering*] was well worth taking" said one student, while another replied "Engineering was somewhat how I envisioned it" (student responses, January questionnaire). In the March focus group following the conclusion of the course, students supported these sentiments. One student commented about the course that "everyone going into engineering should take it, for sure" (student response, focus group interview, March 5, 2010).

Connecting Subject Disciplines

In their responses September questionnaire, students recognized the interdisciplinary nature of engineering. Science or science and mathematics were mention in six of 11 definitions of engineering (55%): "Engineering is a basis of hands-on work which applies concepts of physics, technology, chemistry and mathematics" (student response, September questionnaire) read one definition. Technology was mentioned explicitly in only two definitions, but was implicit in five others, such as: "Using knowledge from sciences such as physics or chemistry to construct engines, bridges, buildings, ships, chemical plants, etc." (student response, September questionnaire). In describing their perceptions of engineers' personal traits, seven of 11 respondents (64%) identified well-rounded knowledge and skills, especially in science and mathematics, as one of the predominant characteristics of engineers.

When asked to differentiate between science and engineering, two students said that engineering addresses how, while science addresses why. Two students saw the natural world as the realm of science, and the human-made world as the realm of engineering and suggested that science is a fixed set of unchanging knowledge and facts, while engineering is constantly changing. One student said "It [engineering] differs from science because it is designed by humans, whereas science is natural substances. [Engineering is] always looking for improvements; science is a set thing" (student response, September questionnaire). The use of science by engineers, or science as a part of engineering was mentioned in four of 11 responses (36%).

Introduction to Engineering integrated selected expectations from mathematics, physics, and technological design. However, students were not evaluated on these expectations, but rather were evaluated on expectations from the *Interdisciplinary Studies* curriculum document. Although prior or concurrent completion of mathematics, physics, and technological design courses were recommended for students enrolling in *Introduction to Engineering*, they were not prerequisites, and could not be made prerequisites under the *Interdisciplinary Studies* curriculum. As a result, students came into the course with a wide range of knowledge and skills from the related subject disciplines.

The mathematics and science content of the course were implicit in the assigned projects, rather than taught as explicit lessons. For instance, in the cardboard chair project, students used mathematics in the form of measurement and statistics to collect and analyse anthropometric data which were to be applied to the design of the chair. The use of physics was required for students to design and execute structural tests and to analyse the forces acting on a loaded chair. For the Goldberg machine project, students were required to analyse and model the physics acting in each step, either before or after the step was constructed (see Appendix B). For one step, students videotaped a projectile and used software to approximate the quadratic equation of its parabolic path, and to predict horizontal distances for different launch angles. The preliminary design of another step required a rising helium balloon to push up a piece of letter-size paper. Students had to estimate the lifting force provided by the balloon by approximating the volume of helium in the balloon and calculating the buoyant force based on the difference between the density of helium and the density of air.

Students recognized the mathematics and science content in the course, but often commented that it was not presented in the usual way. On the November and January questionnaires, students that commented on the different approach to mathematics and science were positive or neutral in their response to it. None were negative. One student said "It's [*Introduction to Engineering*'s] better than math because when you're using math it applies directly to what you're doing" (student response, November questionnaire). Students who had experience in a number of technological education courses commented that there was more mathematics and science in *Introduction to Engineering* than was found in the technological education courses.

Although a few students found the mathematics and science content difficult, students more frequently indicated that the content was not challenging enough. Several commented that the mathematics and science content was appropriate for the course, but others said that they were expecting higher levels of difficulty in these areas. As expressed by one student, "They [mathematics and science] have actually been rather light in this course, really just using knowledge already learned" (student response, November questionnaire). I did not have access to students' questionnaire responses during the semester, but some students verbally expressed their desire for more challenging mathematics and physics in the projects. As the semester progressed, it became apparent that one of the challenges for me as the teacher was how to infuse a higher level of mathematics and physics into the course without making the projects unfairly difficult for students without prior knowledge and skills in those disciplines.

The technological design content of the course had to be taught explicitly for those students coming into the course with no prior knowledge, especially for the three-dimensional computer modelling project. Students unfamiliar with the software had to be taught how to use it or they would be unable to do the project. In other projects, students who had taken technological design courses used their knowledge and skills in the design and presentation of their projects. In the cardboard chair project, for example, these students used three-dimensional sketching skills as well as AutoCAD and Inventor software to create scaled technical drawings and computer models of their designs. As the teacher of the course, this inconsistency in students' prior knowledge presented some difficulty in the design, execution, and evaluation of the students' projects.

Anticipating this disparity in students' knowledge and skills, I asked students to complete an information sheet indicating the Grade 11 and 12 mathematics, physics, and technological education classes they had taken or were taking concurrently. Using this information, I set the groups for the cardboard chair project such that each group had a balance of knowledge and skills in all the subject disciplines. However, in my observations of the class throughout the semester, I noted that students' lack of prior knowledge inhibited their ability to complete some projects fully or in a timely manner.

From my observations, students who had taken technological design had a distinct advantage in completing the mechanical computer model. Students who had not taken university preparation mathematics had difficulty understanding the sinusoidal motion of the mechanical models. Students who had not taken physics had difficulty modeling the physics of their assigned steps in the Goldberg machine. One student observed "In our final project, though, there was science that a non-science student couldn't do, like figuring out the physics." (student response, January questionnaire).

One student made an unexpected connection between the subject disciplines integrated into the course. He realized that he could use CAD software in the completion of his physics summative project. Physics students were charged with designing and building a trebuchet. This particular student used Inventor software to create a computer model, render a picture, and produce detailed technical drawings for his trebuchet. He also applied his CAD skills to a mathematics assignment. The student's mathematics teacher asked her classes to come up with a clever, original way to celebrate March 14, which she referred to as "Pi Day" (3.14). The student created a 3D computer model of the π symbol with the digits "3.141592653589…". He placed this model against a background image of the sky and called his creation "Pi in the Sky."

Project-based Learning

Interdisciplinary courses or units of study are often built around projects and solving authentic problems, as was *Introduction to Engineering*. In this respect, the course was unlike a typical academic course and more like a TE course, which are mandated by the Ontario curriculum to be project-driven (Ministry of Education, 2009). Interdisciplinary study and project-based learning have much in common, including authentic problem solving and a focus on cross-curricular skills. "Project-based learning emphasizes depth of understanding over content coverage; comprehension of concepts and principles, rather than knowledge of facts; development of complex problem-solving skills rather than learning building block skills in isolation" (Newell, 2003, p. 5). Project-based learning also involves teamwork, and changes the role of the teacher from that of expert lecturer to that of advisor and facilitator.

Students recognized that *Introduction to Engineering* was different from a typical academic class, commenting that there were fewer formal lessons, tests, and quizzes, and that class time was typically spent working on projects individually or in a small group. They described their projects as some paperwork, some computer work, and some physical, hands-on building. Mathematics and science were not presented in the way students were used to seeing them, but were applied to their projects. Students who had taken TE courses noted that the project-based nature of *Introduction to Engineering* was similar to those courses, but that this course had more computer work, mathematics, and science.

The project-based nature of the course was well-received by students, and seemed to distinguish the course from their regular academic classes. "A lot more exciting and not so 'classroom-sit-down boring stuff'" (student response, November questionnaire) was how one student described it. "I like how we're always doing things" said another (student response, November questionnaire).

From my interactions with students and observations of the class, it became apparent that for at least two students, *Introduction to Engineering* was the first time that they had conceived of finding a solution to an open-ended problem, worked through a design process, and physically manipulated tools and materials to bring a design into physical reality. For one academically-oriented student, it was the first time he had used an electric drill. Another student, who had tried several different ways to power an electric motor with a solar panel and was trying to solder components to build a circuit from a schematic drawing said, "I'm good with theory, but not always in reality" (personal communication, November 26, 2009). *Introduction to Engineering* provided students the opportunity to solve authentic, ill-defined engineering problems that were not merely pencil-and-paper exercises, but required the fabrication of physical solutions.

Problem solving and teamwork were recurrent themes in the data and were identified by students as two of the most important aspects of the course. Although originally identified as individual themes, problem solving and teamwork were later incorporated into the broader theme of project-based learning. However, the frequency of problem solving and teamwork in the data warrant that they be addressed as sub-themes within project-based learning.

Problem solving. Engineering is about solving problems, and problem solving is at the core of *Introduction to Engineering*. This is consistent with the *Interdisciplinary Studies* curriculum under which it is offered: "In interdisciplinary studies courses, students consciously apply the concepts, methods, and language of more than one discipline to explore topics, develop skills, and solve problems" (Ministry of Education, 2002, p.5). Under the *Interdisciplinary Studies* curriculum, students are not evaluated on the expectations of the related subject curricula, but rather are evaluated on broad, interdisciplinary skills such as problem solving.

Students recognized problem solving as major component of *Introduction to Engineering*. They connected the problem solving in the course to engineering and the nature of engineering work, including designing, building, innovating, and making improvements. Problem solving was a common element in their definitions of engineering, along with innovating, improving, and creating. On the January questionnaire, five of 11 students (45%) listed creativity or open-mindedness as characteristics typical of engineers, since engineering problems are not clear-cut and there are many potential solutions. In the focus group interview, students identified developing problem solving skills as one of the most worthwhile aspects of the course.

The problem solving in *Introduction to Engineering* took a variety of forms. The projects themselves were design problems that had to meet certain criteria within a given set of restrictions. These projects were comprised of many smaller problems that had to be addressed in the course of design and construction. In the cardboard chair project, for example, students developed and executed structural tests on cardboard components. They not only had to devise the tests and the testing apparatuses, but also had to resolve how to apply the results to the design of the chair. They had to analyse the anthropometric data they had collected and apply their analysis to the design of a comfortable chair. They approached the problem by making sketches of potential designs, and then proceeded to make scaled technical drawings that could be used to construct the components of the chair. One group made a small-scale physical model of their chair which enabled them to detect a structural flaw in the design before constructing their chair. Another group opted to create a computer model of the design in order to get a better idea of how the pieces of the chair would fit together.

The problem solving in the course sometimes showed students that the most academically astute students do not always conceive the best solutions. A student who was weaker academically than many in the class spotted a structural flaw in his group's chair design while he was examining a two-dimensional drawing of the design. When I looked at the drawing, I agreed with the student's identification of a structural weak point with the potential for failure. The design had been drawn by a student that was a high achiever academically, but the other student had the innate ability or the spatial sense or the intuition to see where the chair would fail, even though he knew nothing of physics, forces, or stress concentrations.

The machine project was not only an exercise in problem solving, but an exercise in persistence. Students had to design and build a functioning part of the machine and had to ensure that their part worked in concert with the other components of the machine. Each step had to be triggered by the step before it and, in turn, had to trigger the step following it. Although students may have started out with a design in mind, they quickly realized that their designs had to change and evolve as they were developed. Sometimes extensive trial-and-error was necessary to get a step to work, as students realized that what appeared to work on paper did not always work in practice. Almost all steps required some modifications to the original design, while other students came to appreciate firsthand the origins of the expression "back to the drawing board." Even after the individual steps were completed, testing and tweaking were necessary to get the Goldberg machine to function from start to finish (see Appendix B).

In the March focus group, students indicated that improving problem solving skills was one of the most important aspects of the course. This was also reflected on the January questionnaire, where seven of nine respondents (78%) mentioned problem solving in one or more of their responses. From my observations, they relished the opportunity to solve open-ended problems and expressed satisfaction in being able to devise their own solutions. They found that the creative problem solving in the course distinguished it from their other courses: "Thus far, intro to engineering has been more fun than sitting through lectures, and has been more hands on....which is more involving" (student response, November questionnaire).

Teamwork.

Many of the projects in *Introduction to Engineering* were team projects. Although one student expressed dissatisfaction at not being able to pick his own group, students were generally positive about the teamwork environment. The Goldberg machine was a project involving the entire class and, in the focus group interview, students commented that everyone in the class pulled together to create the machine and that developing teamwork skills was one of the most worthwhile understandings they gained from the course. Students often work individually in academic courses, and they seemed to relish the opportunity to work as part of team. One student said that it enabled him to "interact with others in a positive way" (student response, January questionnaire), while another said that the course "widened my mind in terms of working with others and trying to fix a 'problem' or achieve the same goals" (student response, November questionnaire).

The required teamwork varied somewhat depending on the project. For the cardboard chair project, each team consisted of a product engineer who was responsible for the overall design of the chair, a structural engineer who was responsible for the structural elements of the chair, and an ergonomics engineer who was responsible for collecting and analysing the ergonomic data. In the early stages of the project, students had to work with their counterparts from the other groups. This required not only teamwork among group members, but also between groups. For example, the product designer could not design the look of the chair without consulting the ergonomics engineer and the structural engineer. For the Goldberg device, the class developed an overall plan for the machine, and then assigned steps of the machine to individuals or teams of two or three. Even though students were working on one step of the machine, they could not work in isolation because, in the end, the steps had to work in succession.

A problem common to cooperative group work in school was also a problem in *Introduction to Engineering*: equitable sharing of the workload. Some students ended up doing a disproportionately greater share of the work due to ability, work ethic, or the poor attendance of other group members. Although some students were frustrated by this, most were receptive to team projects: "It [the course] allowed for good teamwork skills to be developed" (student response, January questionnaire).

Student Engagement and Affective Outcomes

In their responses on the September questionnaire, preparation for the future was indicated by six of 11 students (55%) as an influence in their choice of elective courses. This was the most frequent response, but five of 11 students (45%) indicated that personal interest, enjoyment, or anticipated success were also considerations that influence their choices.

Student response to *Introduction to Engineering* was overwhelmingly positive. On the January questionnaire, four students described the course as "fun," two said it was "great," and three students described the course as "enjoyable" or "interesting." The course compared favourably to other elective courses and to core courses, with students describing *Introduction to Engineering* as more interesting or appealing than other courses. They affirmed the project-driven nature of the course as more involving and engaging than a passive classroom environment. Students found the course to be useful, either for their postsecondary plans or in the development of broad general skills such as problem solving or teamwork. Students' response to the course is perhaps best expressed in their own words:

> "I'd like to say that it was a great experience. It was well worth taking."
>
> "This course was so much fun and I wish it began in Grade 11 and ended in Grade 12."
>
> "Probably one of the more enjoyable courses in high school." (student responses, January questionnaire)

Most students were engaged on most days of the course, and some often stayed after class to continue working through their lunch period. However, students were not always engaged. Some had low motivation and were distracted by the availability of internet access and its social networking and gaming websites. From my observations, these were the students who did not appear to have an innate interest in the course, but were placed into the course because it fit their timetable and they had no other option. The attendance of these students was also sporadic and their contribution to group projects was less than equitable.

Other students found it difficult to stay motivated for the weeks necessary to complete the projects. The engineering problems posed to students were not simple and straightforward and required weeks of persistent work. Sometimes students lost motivation, especially in the face of adversity or difficulty in completing the projects. In other cases, some seemed to get bored with a project after a few days or weeks. One student suggestion was to establish firmer deadlines to complete projects in order to instil a sense of urgency in students to complete project work.

Students' sense of achievement and accomplishment was perhaps best captured on video on the final day of the course. After weeks of designing, building, adjusting, and tweaking, the Goldberg machine was finally fully assembled and ready for testing on the last day of the semester. It comprised over 20 steps and covered a 10-foot-square area of the classroom floor. It included a solar panel, a wind turbine, a water turbine, an airplane, a train and a train bridge, electric motors, pulleys, gears, and a projectile launcher. Some students went to corral their friends to show them what they had built. Other students' curiosity was piqued and they wandered into the room from the hall. Soon there was a group of 25 or more students gathered around to watch the Goldberg machine in action. In the video of the machine's first test run, the buzz of anticipation can be heard building to cheers as the machine successfully completed its run and raised a Canadian flag. One of the students, looking at the finished Goldberg machine with pride, and a sense of awe at what they had accomplished said to me, "I've never done anything like this before" (personal communication, January 21, 2010).

Summary

The themes that emerged from the data are related to facets of interdisciplinary study. *Introduction to Engineering* connected students to the practice and profession of engineering in the world outside of school through problems, projects, assignments, guest speakers, and a field trip. Students used knowledge and skills from mathematics, science, and technology to design and build projects and to solve engineering problems individually or in teams. The course utilized project-based learning, and students indicated that problem solving and teamwork were the most worthwhile understandings they gained from the course. The mathematics and science in the course were not presented in a familiar way, and some students found that the mathematics and science was not challenging enough. Students with prior knowledge of CAD software had an advantage in some projects.

Students were unanimously positive about their experiences in the course. They found it to be interesting, engaging, and enjoyable. They were receptive to the project-driven nature of the course relative to traditional lesson-based courses, and welcomed the opportunity to work in teams. Their overall understanding of engineering was enhanced, and they would recommend the course to other students, especially those considering postsecondary studies in engineering. The themes that emerged from the data are not isolated, but are all interconnected.

There were some limitations to data collection and analysis in this case. The sample size was small at only 11 participants, which limited the variety of student experiences and perceptions in the study. Because I am the teacher and designer of *Introduction to Engineering,* I had to be conscious about maintaining my objectivity as a researcher. My dual role of teacher and researcher meant that I could not always give my full attention to all events occurring in the classroom, since I still had to fulfill my obligations as the teacher of the course and that role frequently took precedence.

Despite steps taken to mitigate its influence, the inherent power imbalance in the student-teacher relationship must still be considered. Although student responses to questionnaires were anonymous and were not reviewed until after the course had concluded, students may not have been frank in their responses on the questionnaires. The inequity in the student-teacher relationship may have been more of a factor in my personal communications with students and in the face-to-face focus group with students.

Data were triangulated through the collection of artefacts representative of students' work. These samples reinforced my observations of students' activities in the course. A member check was conducted to give students the opportunity to confirm, contradict, or add to questionnaire responses, and I conferred with students continually throughout the semester to ensure that my interpretations of their actions and words were accurate. I consulted with a critical friend to get feedback on my interpretations of the data.

In Chapter 5 I discuss the findings of the study as they relate to the research questions, the related literature, engineering education in the secondary curriculum, and interdisciplinary study in general. Implications for educational practice and theory are made, and directions for future research will be suggested. Finally, some concluding statements are made regarding the place of engineering in the secondary curriculum and engineering as an organizing theme for interdisciplinary study.

CHAPTER 5: DISCUSSION AND IMPLICATIONS

There are more engineers in Canada than there are doctors and lawyers combined (Canadian Institute for Health Information, 2009; Engineers Canada, 2010; Federation of Law Societies of Canada, 2007), and engineering undergraduates represent over 20% of Ontario's undergraduate enrolment (Council of Ontario Universities, 2010). In light of these statistics, engineering is underrepresented in the Ontario secondary school curriculum. It is hardly mentioned in the mathematics and science curricula and engineering is most often used as a label or descriptor in the TE curriculum. In recent years in the US, there has been a call to include engineering in the K-12 curriculum. Proponents of this movement claim that engineering education has the potential to TE and to raise the status of TE, thereby bringing TE into the educational mainstream as part of a well-rounded general education.

This study explored an *Interdisciplinary Studies: Introduction to Engineering* class over the course of a semester, including students' experiences in and perceptions of the course, and the use of engineering as an integrating theme for mathematics, science, and technology. This chapter provides a brief summary of the background of the research problem, the purpose of the study, and the research design and methodology. Based on the findings from this study, implications for engineering education in secondary school will be discussed in the context of engineering in the secondary curriculum and the potential for engineering as an interdisciplinary theme. Directions for further research will be suggested and, finally, some concluding statements about engineering education in secondary school, its place in the secondary school curriculum, and its potential value to students will be made.

Historically, TE has been somewhat separate from academic subject disciplines in both its delivery and its purposes. Deeply ingrained manual skills training practices persist into the 21^{st} century despite attempts at curriculum reform in TE. Resistance to change in education is not unique to TE. Although IDS is not a new idea, it is uncommon in secondary school, despite claims of its many benefits for students. K-12 engineering education is seen by some as a way to integrate TE with academic subject disciplines, raise the profile and status of TE, and bring TE to a broader spectrum of students.

The purpose of this study was to explore students' experiences in and perceptions of an interdisciplinary *Introduction to Engineering* course and to explore the viability of engineering as an interdisciplinary theme for the integration of mathematics, science, and technology in secondary school. The study was a qualitative case study of a single class of *Introduction to Engineering* over the course of a semester.

Because this study was an exploratory study of a phenomenon bounded by space and time, a qualitative case study approach was chosen as the most appropriate research methodology. Data were collected through questionnaires administered to students, the researcher's observations, reflections, and interactions with students, the collection of artefacts representative of students' work, and through a focus group interview with students following the conclusion of the course. Member checks were performed with students throughout the semester and after the conclusion of the course to ensure that the researcher's interpretations of events and questionnaire responses were accurate.

Data analysis was performed by coding textual data and classifying text segments into common themes. The themes that emerged from the data were aligned with facets of IDS: making connections to the world outside of secondary school; making connections between subject disciplines; project-based learning; and, student engagement and affective outcomes. A critical friend was engaged to review the data analysis in order to enhance its validity.

Introduction to Engineering was a positive and worthwhile experience for students, regardless of their postsecondary plans. They found the project-driven nature of the course engaging and welcomed the opportunity to solve open-ended engineering problems as part of a team. Students recognized the mathematics, science, and technology content in the course and made connections between these subject disciplines. They gained a greater appreciation of engineering and recognized the influence of engineering in the world at large and in their day-to-day lives.

The findings of this study can contribute to the research literature on engineering education in secondary schools, including theoretical and existing frameworks for engineering courses, and the potential of engineering to bridge the gap between TE and academic disciplines. *Introduction to Engineering* was designed as an interdisciplinary course and, as such, the findings of the study also inform the literature on IDS as it relates to the research questions in this study.

In Chapter Four, the findings of this study were organized under IDS-related themes that emerged from the data: (a) connecting to the world outside of secondary school, (b) connecting subject disciplines, (c) project-based learning, and (d) student engagement and affective response. These themes are not discrete and do not stand alone, but are interwoven and connected to each other and to the study of engineering in secondary school. For example, students' engagement in and positive response to *Introduction to Engineering* was affected by the project-driven nature of the course, and the projects were interdisciplinary, reflective of authentic engineering problems that required problem solving, teamwork, and higher order thinking skills. The following sections will discuss the findings of the study in the broader contexts of the place of engineering in the secondary curriculum and engineering as an interdisciplinary theme.

The Place of Engineering in Secondary School

Complete engineering courses that include problem solving, reverse engineering, engineering systems, modeling and prototyping, and teamwork have been developed for secondary school (Childress & Rhodes, 2008; International Technology Educators Association, 2004; Onwubiko, 1997). These programs served as models for the development of *Introduction to Engineering*. Proponents of the inclusion of engineering in the K-12 curriculum present many arguments in its favour, including enhancing problem solving skills, facilitating the integration of academic and TE subjects, and improving the rigour and status of TE (Lewis, 2004; Wicklein, 2006; Wicklein, Smith, & Kim, 2009). The findings of this study as they inform some of these arguments will be discussed in the following sections.

Engineering as Technological Education for All Students

Engineering is seen by some as a way to broaden the appeal of TE and raise its status in the eyes of parents and students (Lewis, 2004; Wicklein, 2006). When *Introduction to Engineering* was first offered as an elective course, I expected that it would attract students planning on postsecondary studies in engineering, and would have little appeal for other students. Although many students in the course were intending to apply to university engineering programs, a significant number were not. Some were interested in other university programs, such as business, while others were college-bound or unsure of their future plans. There were also two students who were placed into the course only because it fit their timetables and few other options were available.

Although my expectation was for a homogenous student profile, the diversity of abilities and aspirations of students in the course support the potential for engineering as an area of study that serves a more general purpose as espoused by Lewis (2004) and Wicklein (2006). The students in *Introduction to Engineering* who were not pursuing postsecondary studies in engineering were still positive about their experiences in the class and felt that they benefited from participation in the course. These students indicated that the course enhanced transferable, cross-disciplinary skills such as problem solving and teamwork that could be used in other areas of postsecondary study or in their day-to-day lives.

The general idea that an engineering course can appeal to a wide range of students, and not just those pursuing engineering, is supported by researchers and writers in the field (Gattie & Wicklein, 2007). Kelley and Kellam (2009) state, "It is our belief that technology education, with a focus on engineering design, is as beneficial for students who want to become attorneys, physicians, accountants, business managers, clergy, and writers as it is for future engineers" (p. 39). Furthermore, Merrill, Custer, Daughtery, Westrick, and Zeng (2008) concluded that engineering design concepts can be delivered to a diverse population of students. Based on my findings from the study, the overwhelmingly positive student response to *Introduction to Engineering* supports the position that the study of engineering in secondary school has the potential to benefit all students, and not just those keenly interested in engineering.

Bridging the TE-Academic Gap

One of the impetuses for the development of *Introduction to Engineering* was to integrate TE and academic subjects and to introduce TE concepts and skills to students who might otherwise take a purely academic path that does not include TE. The "blue collar" image for TE persists in secondary school, and many future engineering students do not consider taking TE courses. As a former professional engineer and now a secondary TE teacher, I believe that TE as currently found in secondary schools offers knowledge, skills, and habits of mind that can be of benefit to aspiring engineers. TE integrated with mathematics and physics and presented in the context of engineering, should attract academically inclined students with no previous exposure to TE. However, 10 of 11 students participating in the study had taken at least one TE course prior to or concurrent with *Introduction to Engineering*. Of these 10 students, seven were familiar with me as a teacher through the technological design courses I regularly teach in grades 10 to 12. Although this study involved only one class for one semester, this enrolment pattern suggests that *Introduction to Engineering* as it currently exists in this school did not reach those potential future engineers who had no experience with TE. It is possible that the corollary of this trend is true; that the course attracted students with experience in TE who were looking for more mathematics and science content than their previous TE courses had to offer. Nevertheless, further study would be necessary to ascertain this motive.

Many students observed that *Introduction to Engineering* was more like a TE course than an academic course, but added that the course had more mathematics and physics content than the TE courses they had previously taken. It has been suggested in the literature that the inclusion of engineering in the TE curriculum would increase the rigour and status of TE, and help to elevate parents' and students' esteem for TE to that of other subject areas (e.g., science, mathematics, English) through the curricular framework of engineering and its integrated mathematics and science content (Lewis, 2004; Wicklein et al., 2009). Because *Introduction to Engineering* was offered as a single-credit IDS course, this increased rigour proved difficult to attain.

Since the only prerequisite for the course was any University or University/College preparation course, many students that enrolled in *Introduction to Engineering* did not have the recommended prerequisites in physics and technological design, and could not be evaluated on expectations from those courses. As stipulated by the Ministry of Education (2002) policy document: "In single-credit interdisciplinary studies courses, only achievement of the interdisciplinary studies expectations will be evaluated. Students are not expected to achieve any of the expectations from the other courses" (p.7). Although all students had previously taken a Grade 11 mathematics course, the level of mathematics completed varied, so presumptions could not be made about students' knowledge and skills in mathematics. Because some students' knowledge and skills were limited, and I had to work within the mandated prerequisites and evaluation policies of the interdisciplinary studies curriculum, I could not infuse more advanced mathematics and physics into the projects without putting some of the students at a disadvantage.

Several students, most often those who had taken university preparation mathematics and physics courses and were intending to pursue postsecondary engineering studies, indicated that they found the mathematics and physics content in the course very easy and not enough of a challenge. This broad spectrum of students' prior knowledge proved to be one of the most troublesome aspects of *Introduction to Engineering*. Grouping students based on the courses that they had previously taken, in order to achieve a balance in each group, was one way to mitigate this problem. However, I felt I was doing a disservice to those students who were interested in engineering and would have been more capable in dealing with sophisticated engineering tasks in the course. Also, students who did have background knowledge in mathematics, physics, and technological design tended to contribute more to the group projects and achieve at a higher level, perhaps because they were better equipped to address the engineering design problems presented in the course. Because of the disparity in students' prior knowledge and skills, *Introduction to Engineering's* level of difficulty was not what I had envisioned for a Grade 12 university preparation course. Therefore, positioning *Introduction to Engineering* within the interdisciplinary studies curriculum limited the mathematics, physics, and technological design content I was able to infuse into the course.

The findings of the study show that an engineering-focused course can appeal to a wide range of students and not just those interested in engineering careers. However, the course did not reach students with no prior experience in TE. The study of engineering in secondary school may have the potential to raise the status of TE and integrated TE with other academic subjects. However, *Introduction to Engineering*'s designation as an interdisciplinary studies course may have hindered this potential.

Interdisciplinary Facets of Engineering Education

Engineering education in secondary school and interdisciplinary studies generally share many commonalities. Each theoretical framework is grounded in constructivism (Kelley & Kellam, 2009; Kerka, 1997). Open-ended, ill-defined problems and projects are often the vehicles for learning. Espoused benefits for students include increased motivation and engagement through authentic tasks, and the development of higher-order thinking skills of analysis, synthesis, and evaluation (Kelley & Kellam, 2009; Relan & Kimpston, 1991; Tanner, 1992; Wicklein et al., 2009). The following section will discuss findings of the study as they pertain to the development of students' higher-order thinking skills and to the notion of authenticity in *Introduction to Engineering*.

Higher-Order Thinking Skills

Analysis, synthesis, and evaluation are higher-order categories in the cognitive domain of the original Bloom's taxonomy. These categories were renamed analyze, create, and evaluate, respectively, in Krathwohl's (2002) revision of Bloom's taxonomy. In addition, Krathwohl switched the places of create (synthesis) and evaluate in the hierarchy. Engineering design and problem solving processes, such as reverse engineering a mechanism, or the design, fabrication, and evaluation of prototypes, often reflect these categories (Childress & Rhodes, 2008). It is no surprise then that working through engineering design processes would foster the development of higher-order thinking skills in students (Kelley, 2008; Wicklein et al., 2009).

Engineering analysis is frequently included as a component of proposed and existing secondary school engineering curricula (Childress & Rhodes, 2008; Onwubiko, 1997). The open-ended nature of the projects in *Introduction to Engineering* required students to collect and analyse data, to analyse materials and structures, to reverse engineer, and to integrate their existing skills and knowledge toward the completion of their projects. For example, the Goldberg machine project required students to troubleshoot the machine by analyzing malfunctioning parts and deducing how to affect repairs.

Synthesis played an important role in *Introduction to Engineering* as students were required to integrate subject disciplines, organize information, and plan, design, and build physical products that met the project criteria. When I was developing *Introduction to Engineering*, it was important to me that the course involved the design and fabrication of physical solutions to simulated engineering problems. This is consistent with theoretical frameworks for engineering education that emphasize fabrication and prototyping (Kelley & Kellam, 2009; Wicklein et al., 2009). The opportunity to take ideas and make them reality seemed to be one of the most satisfying aspects of *Introduction to Engineering* for students. Indeed, for some students, it was their first time experiencing an engineering design process from beginning to end.

The evaluation of engineering projects is often described in terms of optimization (Childress & Rhodes, 2008; Merrill et al., 2008). Optimization is striving to maximize the positive aspects of a design while minimizing the negative aspects, thereby achieving the best solution. For example, strength and stability were two of the criteria for the cardboard chair project, but minimizing the amount of material used was another. Material could be added to gain strength and stability, but this meant a less efficient use of material. Students are used to finding the right answers to problems, but there were no right or wrong answers to the problems in *Introduction to Engineering,* only better or worse solutions.

In addition to evaluating their final products, students had to continually test, assess, and evaluate throughout the design process. This approach is consistent with assessment as learning as described in Ontario's *Growing Success* document (Ministry of Education, 2010). Assessment as learning is intended to help students "develop their capacity to be independent, autonomous learners who are able to set individual goals, monitor their own progress, determine next steps, and reflect on their thinking and learning" (Ministry of Education, 2010, p. 27).

Analysis, synthesis, and evaluation are aligned with design processes in existing and proposed secondary school engineering curricula (International Technology Educators Association, 2004, Onwubiko, 1997, Wicklein et al., 2009) and the type of problem solving found in *Introduction to Engineering*. As such, a project-driven engineering course has the potential to develop these higher-order thinking skills in students. The *Interdisciplinary Studies* curriculum document also emphasizes these higher-order thinking skills: "Students need to know new methods and forms of analysis, interpretation, synthesis, and evaluation that will allow them to build on skills acquired through the core curriculum" (Ministry of Education, 2002, p.4).

Problem solving is an important component of existing secondary school engineering courses (International Technology Educators Association, 2004; Onwubiko, 1997) and proposed frameworks for engineering education (Childress & Rhodes, 2008; Kelley & Kellam, 2009). Students enjoyed the problem solving in *Introduction to Engineering* and identified the development of problem solving skills as one of the most worthwhile aspects of the course. The open-ended, ill-defined problem solving in *Introduction to Engineering* facilitated the development of these higher-order thinking skills and student response to the course indicates that they welcomed the opportunity to use and develop these skills.

In addition to the more commonly know cognitive domain, Bloom also defined an affective domain which includes values, attitudes, motivations, and interpersonal relations (Clark, 1999). The highest-order of the affective domain, internalizing values or characterization, includes interpersonal relations or teamwork. Clark describes behaviours in this domain such as working independently, cooperating in a group, and objective problem solving. Wicklein et al. (2009) concluded from their survey of experts in the field of engineering that teamwork should be one of the emphases in an engineering design curriculum.

Students' positive response to the teamwork in the course was one of the surprising findings of this study. In my experience, I have found that students often balk at the prospect of working in a group, especially when those groups are assigned by the teacher. Students were very receptive to the group work in *Introduction to Engineering*, and especially receptive to undertaking the design and construction of the Goldberg device as a whole-class project. Students who were loners or socially awkward seemed to welcome the opportunity to interact with their peers.

Authentic Learning Experiences

Increasing student engagement and motivation and making the curriculum relevant for students through authentic tasks are some of the purported benefits of IDS (Drake & Burns, 2004; Post et al., 1997; Tanner, 1992). Wiggins and McTighe (2005) describe an authentic task as one which is set in a realistic context, requires judgement and innovation, is performance-based, mimics adult situations, and requires a range of knowledge and skills to solve complex, multistage problems. Through authentic problem solving, IDS endeavours to help students make connections between subject disciplines and between school and the world outside of school. Authentic problem solving, it is argued, prepares students for life after school by giving them the opportunity to solve the kind of ill-defined problems they are likely to face in the workplace and in life in general.

Solving authentic engineering problems in a realistic context is a key component of engineering curricula (International Technology Educators Association, 2004; Onwubiko, 1997). In order to facilitate the development of engineering curricula aligned with the practice of engineering, researchers surveyed engineering professionals to ascertain what they perceive as important components of secondary school engineering curricula (Childress & Rhodes, 2008; Wicklein et al., 2009). Kelley and Kellam (2009) emphasized the need for contextual learning in their theoretical framework for engineering education. The projects in *Introduction to Engineering* were designed to be authentic representations of engineering projects. For example, the guest speakers that visited the class reinforced for the students that their activities in class reflected authentic engineers' work, and the field trip to the engineering firm also showed students that the work done in class was similar to the work of practicing engineers.

The potential for engineering as an integrating theme for mathematics, science, and technology has been touted as one the reasons engineering should be included in the curriculum (Wicklein, 2006). As a former engineer who came into education as a second career, my intuition was that mathematics, science, and technology could be readily integrated in an engineering course, and this proved to be the case. Integrating content from mathematics, physics, and technological design into student projects was seamless and did not feel artificial or forced. *Introduction to Engineering* students saw how knowledge and skills they had learned in other classes could be applied in the context of engineering, and it seemed to make the subject matter more relevant for them. One student said "In math I don't see the point in doing it because it essentially means nothing, and isn't helping to finish something like the math in engineering is" (student response, November questionnaire). For this student, the opportunity to apply mathematics in the context of an authentic problem enabled the student to see the relevancy of the mathematics in a way that s/he did not in the academic mathematics course.

Facilitating connections between the classroom and the world outside of school is a common feature of IDS (Clarke & Agne, 1997; Drake & Burns, 2004). Solving authentic engineering problems and interacting with working engineers helped students to see the relevancy of their classroom activities. Students who were interested in engineering careers saw direct connections to their intended postsecondary studies and recognized that the problem solving they were doing in class reflected the work of engineers. All students gained an appreciation that engineering plays a role in their lives and that problem solving skills would likely be important for them no matter what postsecondary path they followed. This reflects the philosophy expressed in the preface to International Technology Educators Association's (2004) *Engineering Design* course guide: "Although all students may not become engineers, they do need problem-solving skills for life in the technologically complex twenty-first century" (p.vii).

Gattie and Wicklein (2007) suggest that students who participate in secondary school engineering programs will be better prepared for postsecondary studies in engineering, since they will already have an understanding of engineering design. One student in *Introduction to Engineering* had attended a local university's information session for prospective engineering students, which included a presentation by students in the school's first-year *Engineering Design* course. In a later conversation with the student, he commented to me that what students were doing in the university *Engineering Design* course seemed "Mickey Mouse" in comparison to *Introduction to Engineering*.

The study of engineering in secondary school is easily adaptable to an interdisciplinary model. The interdisciplinary, project-driven nature of engineering makes it a suitable vehicle for the authentic experiences espoused by proponents of IDS. Engineering design processes facilitate the development of higher order thinking skills, and it has the potential to address many facets of IDS, including connecting subject disciplines, authenticity, problem solving, higher order thinking skills, and collaboration.

Implications for Engineering Education

This section will discuss the implications of the study for engineering education in secondary school. Implications for the secondary school curriculum and for the development, implementation, and promotion of IDS courses at the school level will be discussed. The alignment of *Introduction to Engineering* with curriculum theory will be discussed, and suggestions will be made for further research.

Engineering in the Secondary Curriculum

When I first proposed *Introduction to Engineering* to my school's leadership team, they were almost unanimously in favour of the school offering the course as an elective. Over the next two years, the course was well received by the students who took it, and they all said that it was a worthwhile experience. However, in order for an elective course to survive, a sufficient number of students must opt to take it in order to have a viable class size. *Introduction to Engineering* ran for the first time with 16 students, and the class that was the subject of this study numbered only 12. For the 2010/2011 school year, only 16 students selected *Introduction to Engineering*, and the school leadership team decided to cancel the course because of low enrolment, anticipating that some of the 16 students would be lost through attrition.

Despite a positive response from students, educators, and engineers, the course failed to attract a sustainable number of students as determined by the school's administration. Finding a place for *Introduction to Engineering* in the secondary school curriculum was problematic, since the Ontario mathematics, science, and TE curricula do not offer specific engineering-focused courses. Although the TE curriculum offers courses titled *Computer Engineering, Construction Engineering,* and *Manufacturing Engineering,* these courses do not have expectations that specifically address engineering processes and practices, such as optimization, engineering systems, design envelopes, scientific and mathematical modeling, or engineering ethics. The word engineering is often used merely as a label or descriptor in the TE curriculum. *Introduction to Engineering* was not a mathematics course, it was not a science course, and it was not a TE course. Its existence as an IDS course perhaps diminished the significance of the course in the eyes of students.

An engineering framework is touted as a way to increase the rigor of TE by providing a systematic approach and by integrating TE with mathematics and science.

Because *Introduction to Engineering* was offered under the *Interdisciplinary Studies* curriculum, the only prerequisite mandated by the curriculum was any university or university/college preparation course. As a result, some students came into the course without the recommended prerequisites in mathematics, physics, and technological design. This was one of the major drawbacks of offering the course as an IDS course, but it did not fit anywhere else in the secondary school curriculum.

Introduction to Engineering could be offered as a multiple-credit course, but that would mean that the course would have to address all the expectations from Grade 12 technological design, Grade 12 physics, and at least one Grade 12 mathematics course, in addition to the IDS expectations (Ministry of Education, 2002). Students would earn credits for each of the courses comprising the course. This IDS model would require creative timetabling for students and teachers alike, and I would expect such a model to meet with resistance from many teachers. Such practical considerations are often impediments to IDS (Etim, 2005; Hayes Jacobs, 1989).

A multiple-credit IDS course would comprise most or all of students' timetables for a semester. Either three teachers, one from each area of study, would have to collaboratively teach the course, or one teacher with expertise in all three subject areas would have to teach it. The three teacher model would require extensive collaboration to make the course seamless and truly interdisciplinary, and finding a teacher capable of teaching all three subjects could be problematic. In fact, one of the concerns expressed by my school's leadership team when I first proposed *Introduction to Engineering* was who would be able to teach the course if I were to leave the school. Teachers in Kelly and Wicklein's (2009) study identified learning appropriate levels of mathematics and science and integrating these with TE as major challenges in implementing engineering design in secondary school. Kelly and Wicklein (2009) suggested that these challenges could be addressed through professional development.

Engineering as a secondary school course cannot reach its full potential as a single-credit course, and offering engineering as a multiple-credit IDS course presents problems that call for a willing staff and administration, creative timetabling, and teacher collaboration or very specific teacher expertise. In my experience, most schools would balk at offering a multiple-credit IDS course. If the single-credit model is more plausible for schools, perhaps developers of IDS courses could be given the flexibility establish prerequisites for their courses.

Alternatively, in order to place engineering elsewhere in the curriculum, significant changes could be made at the provincial level to establish a program of engineering courses in the secondary school curriculum, with their own prerequisites and expectations. This model is supported by Lewis (2004) who argued that engineering should be part of the regular curriculum from K-12, rather than a stand-alone course, a special program such as *Project Lead the Way* in the US, or a means to raise the profile of TE through association with mathematics and science.

The growth of the Specialist High Skills Major (SHSM) program in Ontario (Ministry of Education, 2010) may provide an impetus for the development of university preparation engineering courses in the Ontario secondary school curriculum. Many SHSM programs are TE-focused and are mandated to address the needs of students in all postsecondary pathways (apprenticeship, college, university, and workplace). I have been involved as one of the leads in the development and implementation of a SHSM program in the energy sector at my school (i.e., the research study site). At meetings and conferences with other SHSM leads, I have observed that the university pathway is often difficult to address for TE-focused programs. University preparation engineering courses would help to meet the needs of university-bound SHSM students interested in technical careers. Indeed *Introduction to Engineering* is included as one of the courses offered to energy SHSM students at my school.

I believe that engineering would be best located in the TE curriculum, since TE is already project-driven and uses many of the same problem solving models and design processes as engineering. It has been suggested that engineering design can serve as a framework throughout TE, providing a more consistent, rigorous structure for all TE courses (Lewis, 2004; Wicklein et al., 2009). However, past attempts to reform TE and change classroom practices have met with limited success (Petrina & Dalley, 2003; Zuga, 1997). Introducing specific, engineering design-focused courses directed at university-bound students may be more effective in reforming TE. Unfortunately, the Ontario TE curriculum was revised in 2009 and, if anything, moved away from engineering by the removal of engineering-related expectations in technological design. Educators involved in the next revision of the TE curriculum should consider the inclusion of a distinct engineering design course as recommended by other researchers in the TE field.

Engineering Education and Learning Theory

A constructivist approach to learning is often affiliated with IDS (Clarke & Agne, 1997) and project-based learning (Newell, 2003). Many elements of constructivism, such as authentic problem solving, content from a variety of disciplines, student-centered learning, and collaboration, can be found in IDS (Roelofs & Terwel, 1999). Purported benefits of constructivism for students include increased engagement and motivation through relevant and authentic activities, and the development of higher-order thinking skills, transferable skills, and social and teamwork skills (Educational Broadcasting Corporation, 2004), which also parallel the touted benefits of IDS (Drake & Burns, 2004; Post et al., 1997).

Kelley and Kellam (2009) used constructivist theory as the foundation of their framework for an engineering design approach to TE. The findings of this study support the benefits of a constructivist approach to learning in engineering education: students found the authentic, project-driven nature of the course engaging and motivating; the projects required students to integrate subject disciplines; the course focused on higher-order thinking skills and transferable skills such as problem solving; the teacher most often acted as a facilitator, and students were often required to work collaboratively as part of a team.

Although constructivism may be a valid theory of learning for IDS in general and engineering education in particular, the education system is often slow to change or embrace new ideas, so innovative approaches like IDS flounder and do not gain widespread acceptance (Clarke & Agne, 1997). A constructivist approach to TE will require teachers to change longstanding manual skills training practices rooted in behaviourism (Becker, 2002). The findings of this study may inform the arguments of administrators, teachers, curriculum leaders, curriculum writers, or others who wish to implement IDS or engineering education based on a constructivist theory of teaching and learning.

Further Research

Much of the discourse around engineering education in secondary school has been around the rationale for engineering in secondary school, perceptions of engineering, proposed course content, and surveys of experts in the field. Although some recent research has been done involving students at the classroom level, such as Merrill et al.'s (2008) study of the delivery of core engineering concepts to secondary students, and Kelley's (2008) study of engineering design students' cognitive processes, classroom level research that directly involves students is still an area in need of further research. For example, classroom action research (Bencze, 2010; Merrill, 2004) and also collaborative action research (Fazio, 2009) might be conducted over several semesters to ascertain the efficacy of an engineering course in improving students' problem solving skills or their preparation for postsecondary study. Johnson and Daugherty (2008) suggested further research in TE in areas such as cognition, creativity, problem solving, and the inclusion of engineering design in the curriculum.

Much of the research in this study involved student perceptions and experiences, which can serve as indicators for future research directions. Although students involved in the course touted its value, the course was not well-subscribed and was regrettably cancelled for 2010/2011. Research into students' perceptions and attitudes about engineering, interdisciplinary study, and TE may provide insight into the promotion of engineering in secondary school, as well as other IDS courses. Students indicated that their problem solving skills had improved from their participation in the course, and perhaps this could be studied in some measurable way. Another research direction would be a longitudinal study tracking students following graduation to see if participation in the course benefited them in their postsecondary endeavours.

Conclusions

Introduction to Engineering was the product of my engineering education and experience along with my experience as a teacher of technological design, construction technology, and mathematics. This study provided the opportunity for me to investigate engineering as an integrating theme for mathematics, science, and technology, and to explore students' experiences in and perceptions of an engineering course.

Engineering is a viable and natural theme for the integration of mathematics, science, and technology, although it needs to find a curricular (and political) place in the secondary school curriculum. A project-driven engineering design course focusing on solving ill-defined problems has the potential to enhance students' understanding of engineering, to improve higher-order thinking skills, and to help students see the relevance of the mathematics and science they have learned in other courses.

Introduction to Engineering was a positive and worthwhile experience for students, regardless of their postsecondary destinations. Although the number of students who opted to take the course was disappointing, the reaction of students that did enrol was encouraging. I believe that engineering education in secondary school can be beneficial for students and that it has the potential to introduce TE to a wider range of students, including those who may not currently consider choosing TE courses. It is my hope that, informed by the growing body of literature on engineering in K-12 education and studies including this study, curriculum writers will be motivated to include engineering in the next revision of Ontario's TE curriculum.

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Appendix A

Observational Protocol

Observational Fieldnotes: *Interdisciplinary Studies: Introduction to Engineering*

Subject of Observation: (e.g. activity, artefact, student behaviour, group behaviour, student-student interaction, student-teacher interaction)

Setting: Observer: PW

Time: Date:

Length of Observation:

Descriptive Notes	Reflective Notes

Appendix B

Samples of Student Work

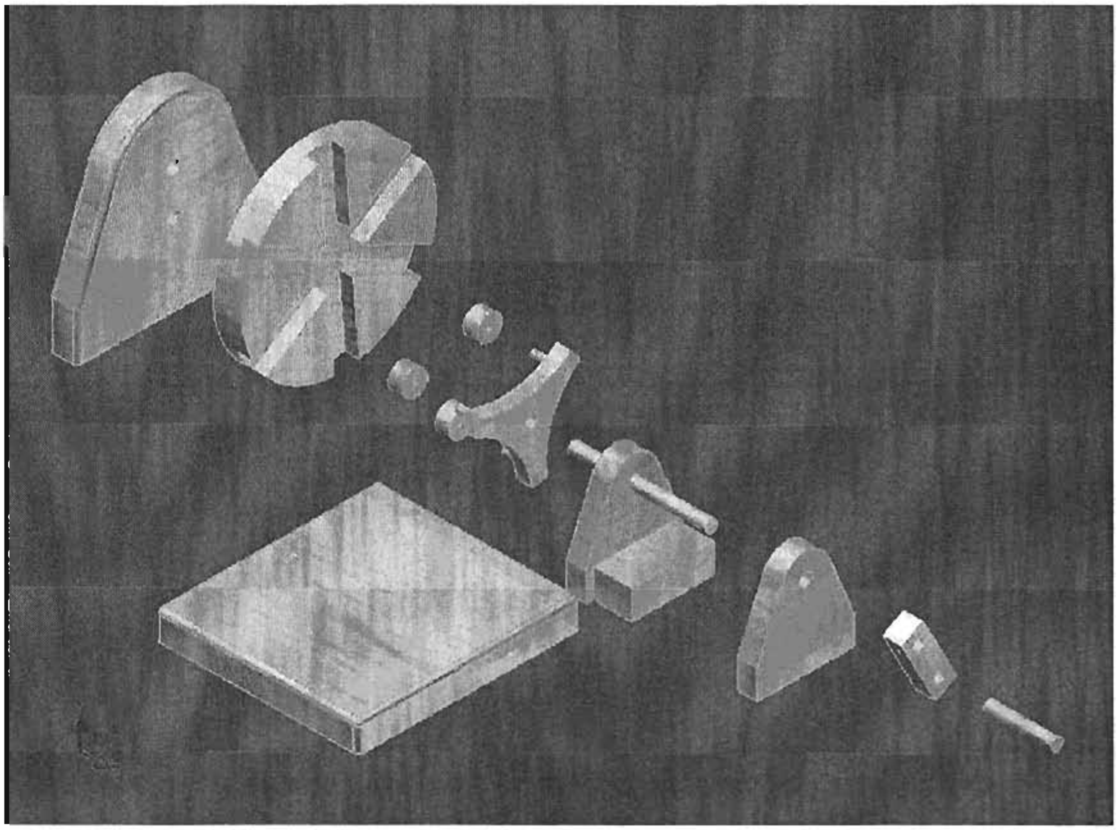

Figure 1. Exploded view of 3D computer model

Students used Autodesk Inventor three-dimensional parametric modelling software to create function computer models of mechanism. This involved creating a computer model of each part, assembling the parts, and simulating the function of the mechanism. Figure 1 is a screen shot of a presentation file which shows an exploded view of a mechanism. A presentation file is an animation showing how the parts are assembled.

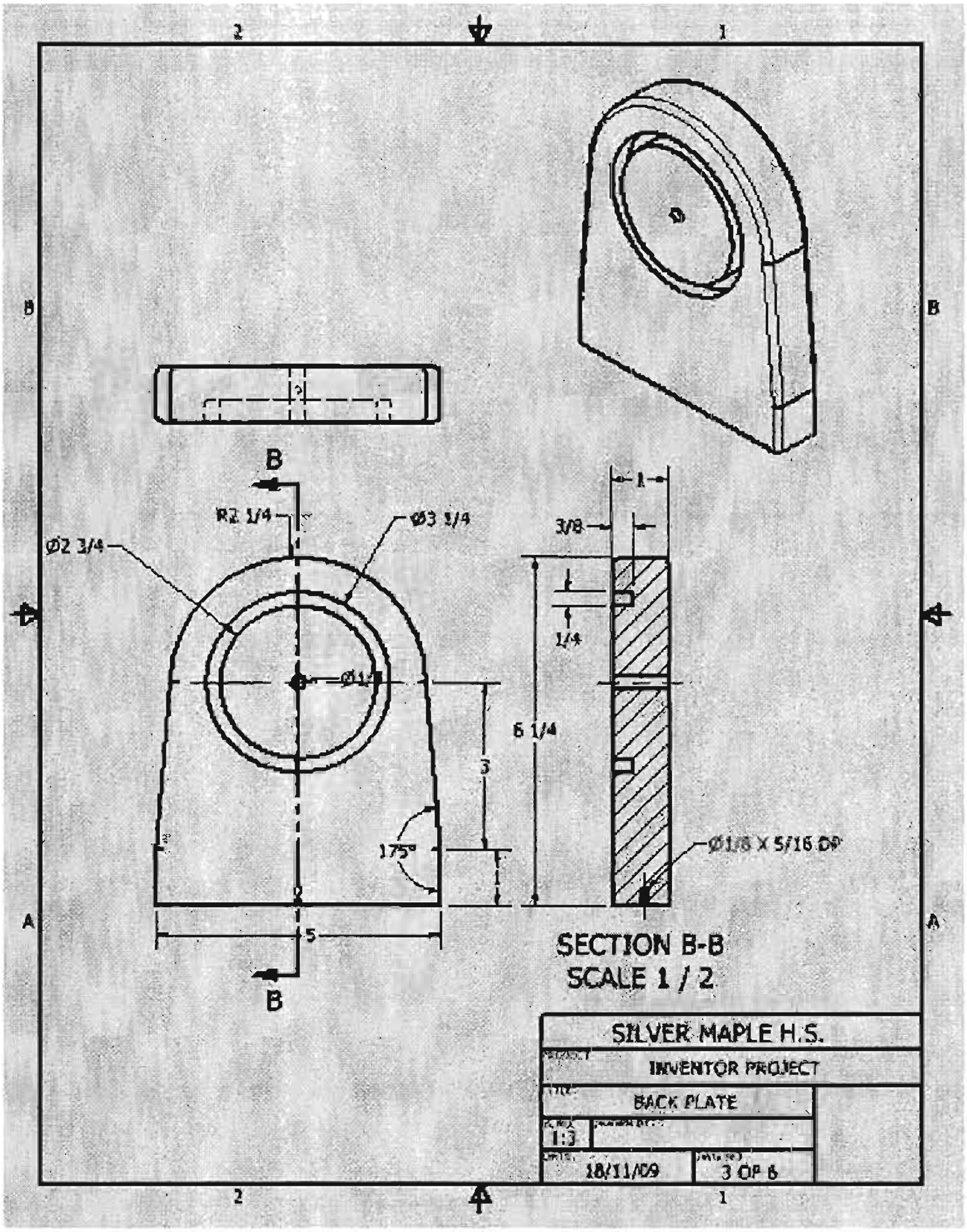

Figure 2. Sample Part Drawing for 3D Computer Model

Using Autodesk Inventor, detailed, dimensioned orthographic and isometric technical drawings of the mechanism and its parts were generated from the computer models.

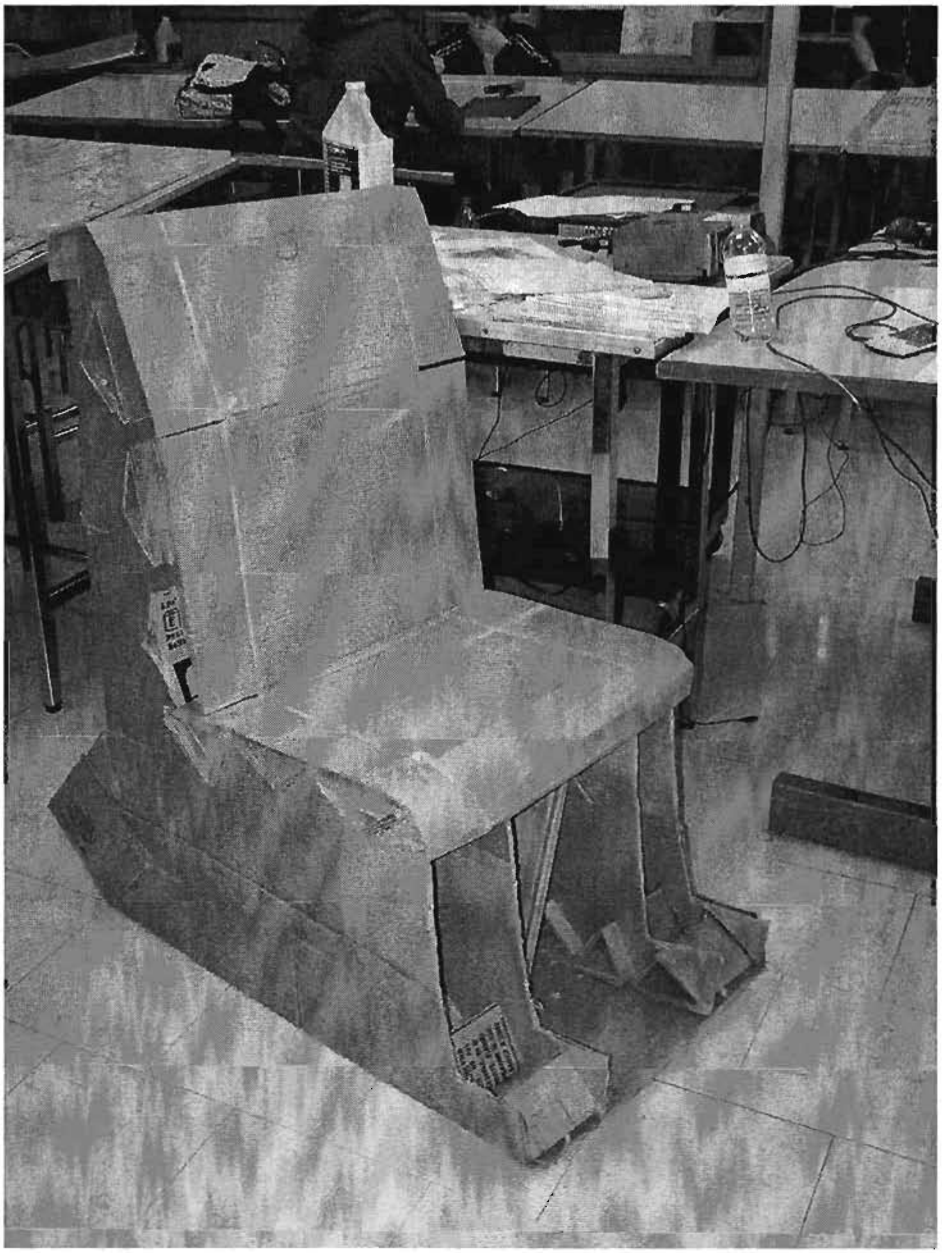

Figure 3. Completed Cardboard Chair

In the cardboard chair project, students were required to construct a chair using only corrugated cardboard and glue. The chair was required to be comfortable, aesthetically pleasing, and capable of supporting 200 pounds.

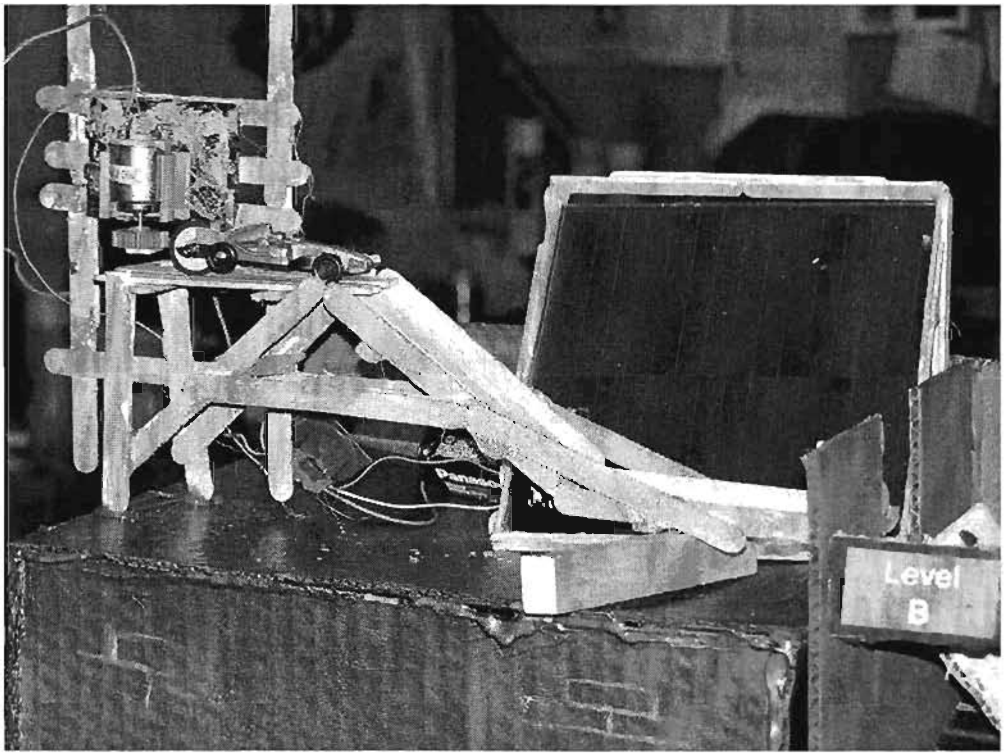

Figure 4. First Step of Goldberg Machine

The Goldberg machine was activated by shining a flashlight on the photovoltaic cell pictured in Figure 4. The electric current from the photovoltaic cell started the electric motor. An arm attached to the motor spun around and pushed the toy car, sending it down the ramp.

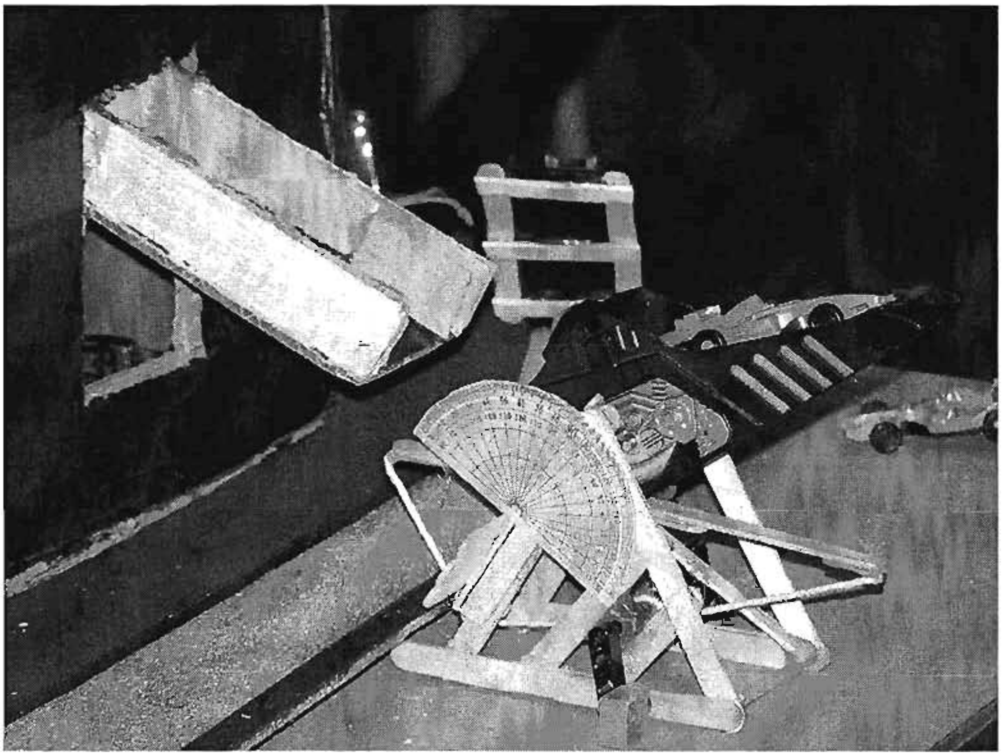

Figure 5. Projectile Launcher Step of Goldberg Machine

The toy car in Figure 5 is loaded into a spring-loaded launcher. Students varied the angle of launch and used video, projectile motion equations, and graphing software to determine how far and how high the car would travel . An adjustable platform was used to precisely set the launch angle.

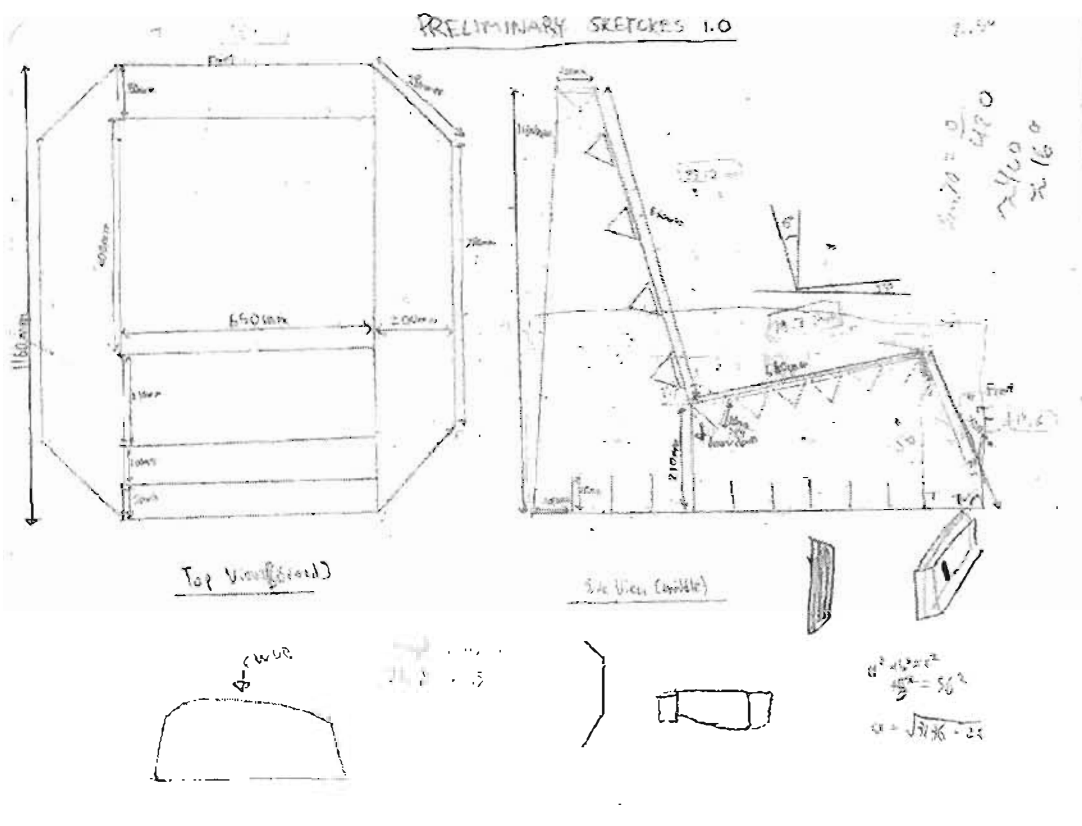

Figure 6. Cardboard Chair Sample Design Sketches

The cardboard chair design teams included an ergonomics engineer, a structural engineer, and a product design engineer. The product designer made preliminary sketches of the overall design of the chair in consultation with the other team members.

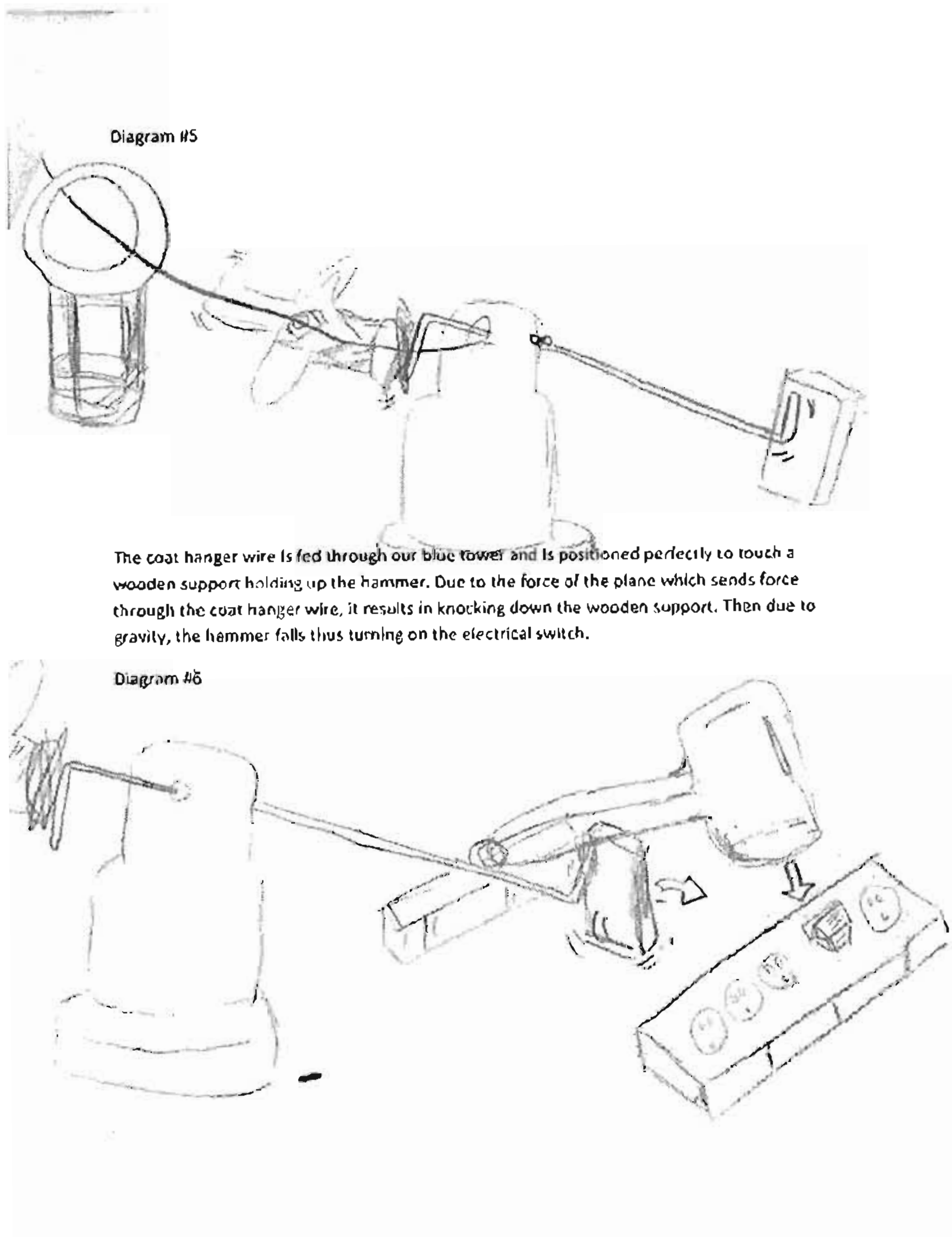

Figure 7. Goldberg Machine Sample Design Sketches

Students sketched designs for each step of the Goldberg machine. Invariably, adjustments had to be made as fabrication progressed.

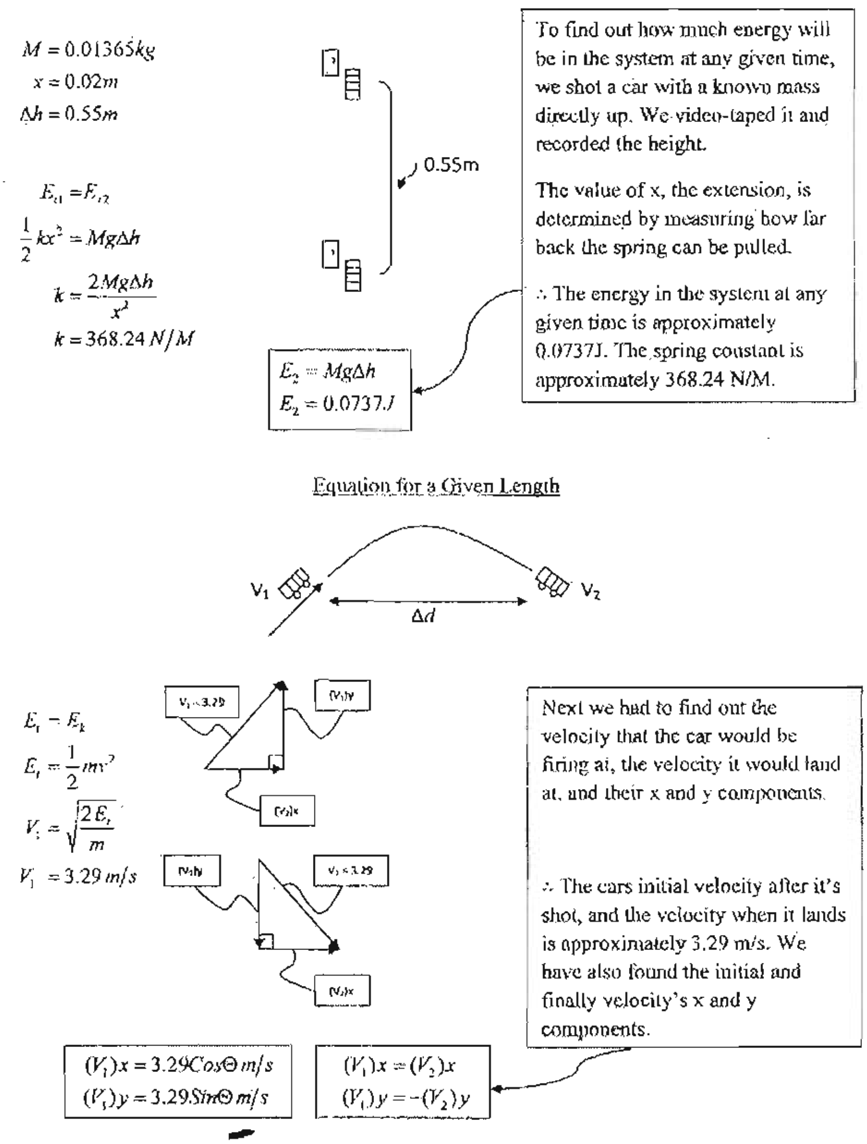

Figure 8. Goldberg Machine Sample Physics Calculations

Students were required to model the physics involved in each step of the Goldberg machines, making any necessary assumptions and approximations.

Appendix C

Student Questionnaires

Project: *Introduction to Engineering*: A Case Study of an Interdisciplinary Course in Math, Science, and Technology

Date: September 2009

The purpose of this study is to explore perceptions of the integration of technological education with academic subjects for university-bound Grade 12 students enrolled in *Interdisciplinary Studies: Introduction to Engineering*.

Please note that you do not need to identify yourself in anyway on this questionnaire in order to maintain confidentiality and anonymity.

This study will not comprise part of your course work for *Introduction to Engineering*. Participation or non-participation in the study will not affect the assessment and evaluation of your work in any way, for this course.

Note that when completing the questionnaire there are no right or wrong answers. Feel free to skip questions that you feel uncomfortable answering or are unsure of how to respond.

Student Information

Grade: Gender: M / F

Post-secondary plans:

1a) What influences your decisions in choosing elective courses?

1b) Why did you decide to take this course?

2a) Have you taken any tech courses in high school? If yes, which courses?

2b) Have you taken any interdisciplinary courses before? If yes, please give a brief description of the course(s).

3) Do you anticipate that this course will have importance for your post-secondary plans? Why or why not?

4a) How would you define engineering?

4b) How do you think engineering differs from science?

4c) What knowledge, skills, aptitudes, and personal characteristics do you think engineers typically possess?

Project: *Introduction to Engineering*: A Case Study of an Interdisciplinary Course in Math, Science, and Technology

Date: November 23, 2009

The purpose of this study is to explore perceptions of the integration of technological education with academic subjects for university-bound Grade 12 students enrolled in *Interdisciplinary Studies: Introduction to Engineering.*

Please note that you do not need to identify yourself in anyway on this questionnaire in order to maintain confidentiality and anonymity.

This study will not comprise part of your course work for *Introduction to Engineering.* Participation or non-participation in the study will not affect the assessment and evaluation of your work in any way, for this course.

Note that when completing the questionnaire there are no right or wrong answers. Feel free to skip questions that you feel uncomfortable answering or are unsure of how to respond.

Student Information

Grade: Gender: M / F

Post-secondary plans:

1) Thus far in the semester, how does the interdisciplinary course compare to regular math and science courses, other core courses (such as English or the social sciences), or other elective courses (such as tech, the arts, or physical education)?

2) If you have taken or are taking any tech courses, how does the tech in the interdisciplinary course compare to your other tech courses?

3) What do you think about the math and science content of the interdisciplinary course thus far?

4) How has the course thus far affected your understanding of engineering?

5) What other information would you like to add about your experiences in the interdisciplinary course thus far?

Project: *Introduction to Engineering*: A Case Study of an Interdisciplinary Course in Math, Science, and Technology

Date: January 2010

The purpose of this study is to explore perceptions of the integration of technological education with academic subjects for university-bound Grade 12 students enrolled in *Interdisciplinary Studies: Introduction to Engineering*.

Please note that you do not need to identify yourself in anyway on this questionnaire in order to maintain confidentiality and anonymity.

This study will not comprise part of your course work for *Introduction to Engineering*. Participation or non-participation in the study will not affect the assessment and evaluation of your work in any way, for this course.

Note that when completing the questionnaire there are no right or wrong answers. Feel free to skip questions that you feel uncomfortable answering or are unsure of how to respond.

Student Information

Grade: Gender: M / F

Post-secondary plans:

1) How did the interdisciplinary course compare to regular math and science courses, other core courses (such as English or the social sciences), or other elective courses (such as tech, the arts, or physical education)?

2) If you have taken or are taking any tech courses, how did the tech in the interdisciplinary course compare to your other tech courses?

3) What did you think about the math and science content of the interdisciplinary course?

4a) What is engineering?

4b) How does engineering differ from science?

4c) What knowledge, skills, aptitudes, and personal characteristics do engineers typically possess?

5) What information would you like to add about your experiences in the interdisciplinary course thus far?

Appendix D

Brock Research Ethics Board Clearance

Brock University

Office of Research Services
Research Ethics Office
St. Catharines, Ontario, Canada L2S 3A1
T: 905-688-5550, Ext. 3035/4876 F: 905-688-0748

www.brocku.ca

DATE: August 31, 2009

FROM: Michelle McGinn, Chair
Research Ethics Board (REB)

Michelle K. McG

TO: Dr. Xavier FAZIO/WHITE, Education
Paul White

FILE: 09-024 FAZIO/WHITE
Masters Thesis/Project

TITLE: Introduction to Engineering: A Case Study of an Interdisciplinary Course in Math, Science, and Technology

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The Brock University Research Ethics Board has reviewed the above research proposal.

DECISION: Accepted as clarified.

This project has received ethics clearance for the period of August 31, 2009 to June 30, 2010 subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The clearance period may be extended upon request. ***The study may now proceed.***

Please note that the Research Ethics Board (REB) requires that you adhere to the protocol as last reviewed and cleared by the REB. During the course of research no deviations from, or changes to, the protocol, recruitment, or consent form may be initiated without prior written clearance from the REB. The Board must provide clearance for any modifications before they can be implemented. If you wish to modify your research project, please refer to http://www.brocku.ca/researchservices/forms to complete the appropriate form Revision or Modification to an Ongoing Application.

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-Council Policy Statement requires that ongoing research be monitored. A Final Report is required for all projects upon completion of the project. Researchers with projects lasting more than one year are required to submit a Continuing Review Report annually. The Office of Research Services will contact you when this form *Continuing Review/Final Report* is required.

Please quote your REB file number on all future correspondence.

MM/law

Appendix E

Introduction to Engineering Course Outline

Silver Maple High School
IDC4U – Interdisciplinary Studies: Introduction to Engineering

Course Outline

Teacher Name	CHATT Address:	Website
Mr. P. White	whitep@[redacted]	http://[redacted]/~whitep
	Office Hours	Room S106/107

This course combines the expectations of *Interdisciplinary Studies, Grade 12, University Preparation* with selected expectations from Mathematics, Physics and Technological Design.

In interdisciplinary studies courses, students consciously apply the concepts, methods, and language of more than one discipline to explore topics, develop skills, and solve problems. These courses are intended to reflect the linkages and interdependencies among subjects, disciplines, and courses and their attendant concepts, skills, and applications, and are more than the sum of the disciplines included. In an unpredictable and changing world, interdisciplinary study encourages students to choose new areas for personal study and to become independent, lifelong learners who have learned not only how to learn but also how to assess and value their own thinking, imagination, and ingenuity in decision-making situations (The Ontario Curriculum, Grades 11 and 12, *Interdisciplinary Studies*, 2002, p.5).

This course will allow students to explore the practice and profession of engineering. Through a series of design/build projects, students will integrate knowledge and skills from math, physics, and technological design in the design, construction, testing, and evaluation of structures, mechanisms, products, and systems. Students will examine the engineering profession, its Code of Ethics, and its governing bodies. They will analyse the impact of engineers and their works on individuals, society, the economy, and the environment.

What will you be expected to learn? (Key Learnings)

In this course, you will be expected to provide evidence that you can:

Theory and Foundation:

- demonstrate an understanding of the key ideas and issues related to each of the subjects or disciplines studied;
- demonstrate an understanding of the different structures and organization of each of the subjects or disciplines studied;
- demonstrate an understanding of the different perspectives and approaches used in each of the subjects or disciplines studied;
- demonstrate the skills and strategies used to develop interdisciplinary products and activities.

Processes and Methods of Research

- be able to plan for research, using a variety of strategies and technologies;
- be able to access appropriate resources, using a variety of research strategies and technologies;
- be able to process information, using a variety of research strategies and technologies;
- be able to assess and extend their research skills to present their findings and solve problems.

Implementation, Evaluation, Impacts, and Consequences

- implement and communicate information about interdisciplinary endeavours, using a variety of methods and strategies;
- evaluate the quality of interdisciplinary endeavours, using a variety of strategies;
- analyse and describe the impact on society of interdisciplinary approaches and solutions to real-life situations;
- analyse and describe how interdisciplinary skills relate to personal development and careers.

<u>*Major Areas of Study:*</u>

Engineering and Society:	***history of engineering; human, societal, economic & environmental considerations; engineering ethics; safety; the engineering profession***
Engineering Design:	***design processes; engineering principles; creativity in engineering; engineering practice***
	identifying problems; designing, building & testing; trade-offs; reverse engineering; research, development & experimentation
Engineering Analysis:	***modeling; application of math & science; measurement & data collection; optimization***
Engineering Communication:	***computer applications; technical presentations, graphics & reports; creating and interpreting technical drawings; CAD; 3D visualization;***
Engineering Science:	***use of computer technology; ergonomics; tool skills; manufacturing; material science***

Appendix F

Student Project Outlines

IDC4UE: Introduction to Engineering

Chair Design Project

Design Brief:

Design and build an ergonomically correct chair based on anthropometric data collected from students in the class. The chair must be able to support a 200-pound person, and be engineered with a factor of safety determined by the design team. The chair will be made exclusively from corrugated cardboard and glue and must make efficient use of design materials.

Specifications:

The chair must have a seat and a back. Arms are optional.

Measurements for the chair will be based on anthropometric data collected from students in the class.

Required angles: Back tilt = 45-60 degrees   Seat lift under legs: 15 degrees

The chair may have no fewer than 3 legs, if the legs are separate.

The chair must safely and steadily support a person who weighs 200 pounds.

The chair must be comfortable to sit in.

The chair must be made from corrugated cardboard.

Glue can be used for the outer skin of the chair and to laminate sheets of cardboard together. No more than 3 sheets may be laminated.

Tape may be used as temporary support only. None may be part of the final solution.

The finished appearance of the chair should be aesthetically pleasing.

The Design Team

The Structural Engineer

The structural engineer is responsible for:

1. The initial design and testing of materials, joints, and connections.
2. Computations of ultimate strength and factors of safety
3. Structural drawings (two cross sections)
4. The structural analysis of the prototype, the structural stability of the prototype, and the structural journal.

The Ergonomics Engineer

The ergonomics engineer is responsible for:

1. Collection of anthropometric data.
2. Ensuring that all dimensions meet ergonomic parameters and constraints on all drawings.
3. Dimensioned orthographic and isometric drawings. Dimensions of model and prototype.
4. The ergonomic journal and the analysis of the prototype.

The Product Design Engineer

The product design engineer is responsible for:

1. Compiling the brainstorming sketches (minimum 3 from each group member).
2. Creating a 3D design sketch for the design
3. Creating a 3D computer model and technical drawings.
4. Final design solution and directing fabrication.
5. Ensuring that construction of the chair meets all design specifications and constraints.

THE RUBE GOLDBERG MACHINE

The Challenge: To raise a Canadian flag.

Specifications

1) The machine must have no fewer than 20 distinct steps. A "step" is a transfer of energy from one action to another action. Identical transfers of energy in succession (for example, falling dominoes) should be considered one step.

2) The machine must be contained in an imaginary box 6'W x 6'L x 6'H.

3) No combustibles, open flames, explosives, hazardous materials or live (or for that matter, dead) animals are allowed.

4) Projectiles and any loose or flying objects must be contained in the 6'x 6' x 6' space.

5) One cycle of the machine may take no more than two minutes. Most take considerably less. Once a cycle is started, no human intervention is allowed to keep it going. It must be possible to reset the machine in 20 minutes or less.

6) The machine must have a unifying **energy** theme.

7) The Goldberg device must include the following:

wheel	gears
wedge	1st, 2nd, and 3rd class levers (1 of each)
pulley	inclined plane to **raise** a load
screw	a projectile
hydraulics or pneumatics	a vertical or horizontal truss
Renewable Energy Education Set	

Each of the above must be a working part of the device and included in one of the steps. For example, a screw that is simply holding parts together does not count.

8) You are encouraged to use a variety of materials, including "found" materials, especially to establish your theme. You do not have to make everything in the machine, but you cannot use Lego, Meccano, or other building toys as your primary material (A little is OK).

9) The geometry and physics of each step must be calculated and approval must be given ***before*** commencing construction of the step.